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Technical Paper 387

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ENGINE SERVICE TESTS OF INTERNAL-COMBUSTION ENGINE LUBRICATING OILS MADE FROM CALIFORNIA CRUDE PETROLEUM

BY

MARTIN J. GAVIN and GUSTAV WADE

A COOPERATIVE INVESTIGATION BY THE BUREAU OF MINES
AND THE AMERICAN PETROLEUM INSTITUTE

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PREFACE

The supply of oil suitable for the lubrication of industrial, marine, and automotive equipment is very largely controlled by the types and quantities of crude petroleum available for refining. In the early days of industry animal and vegetable fats and oils, such as lard oil, tallow oil, sperm oil, and castor oil, were used almost exclusively, and even to-day for certain purposes these oils are probably superior to any known substitute. For example, in "running-in" a close-fitting machine bearing lard oil is often used, as it has the property of penetrating between metal surfaces and maintaining an oily film under great pressure. This property also makes it a valuable lubricating oil for lathe tools and other metal-cutting equipment. Certain marine-animal oils are known to be eminently suited for lubricating fine machinery, such as clocks and chronometers. For the general lubrication of engines, motors, and other machinery however, it is necessary to rely on petroleum oils.

Although the output of lubricating oils is a relatively small part of the total production of the petroleum refineries in this country, the following table shows that the manufacture of petroleum lubricating oils constitutes an important industry in itself.

Yearly production of petroleum lubricating oils

Year	Gallons	Year	Gallons
1917	754, 000, 000	1922	979, 000, 000
1918	841, 000, 000	1923	1, 097, 000, 000
1919	847, 000, 000	1924	1, 155, 000, 000
1920	1, 047, 000, 000		
1921	878, 000, 000		7, 598, 000, 000

The production of animal and vegetable oils in this country is larger in the aggregate than the production of petroleum lubricants. As animal and vegetable oils, however, are used largely to make such products as paints, varnishes, and soaps, and, moreover, are an important part of our food supply, very little of the total output is available for lubrication. This statement is confirmed by the fact that at the beginning of 1925 petroleum lubricants sold at wholesale prices ranging from 10 to 50 cents per gallon, whereas the prices of animal and vegetable oils ranged from 60 cents to $2 per gallon. Obviously, if any large demand were to be made on the supply of these fatty oils, prices would at once increase, so that the oils could not be used economically for general lubrication.

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Two distinct types of lubricating oil are made from petroleum, and they differ fully as much in their characteristics as do anthracite and bituminous coal. The terms "paraffin base" and "naphthene base" are often used to describe these oils, but these terms require definition and explanation. In brief, it can be said that a "paraffin-base" oil is mainly composed of hydrocarbons with relatively high boiling points, low specific gravities, and low viscosities. A "naphthene-base" oil is composed of hydrocarbons with relatively low boiling points, high specific gravities, and high viscosities. Probably different series of hydrocarbons predominate in different oils, but few data are available to show what series are present or in what proportions in any commercial lubricating oil. Such analyses as have been made, however, indicate the predominance of cyclic compounds—in other words, "paraffin-base" lubricants contain paraffin hydrocarbons only as minor impurities. The chemistry of petroleum lubricants is a subject that needs investigation.

Although from the standpoint of the chemist the subject is obscure, practical experience has shown that for most purposes suitably refined oils of either base may be used with equal satisfaction. Certain differences in behavior do exist, however, and in selecting an oil for any particular purpose it is important that proper specifications, based on actual service needs, be used; that is, a specification that would cover a satisfactory paraffin-base oil might not insure good service if applied to a naphthene-base oil, and vice versa.

Furthermore, the requirements for different types of service differ. One can not assume that because an oil must have certain characteristics for one class of service it must also have the same characteristics for another class of service. The present paper well illustrates this fact. That oil for use in steam turbines will be satisfactory in proportion to its resistance to emulsification with water has long been recognized. To manufacture an oil for use in steam turbines requires especial care and skill; generally, therefore, a nonemulsifying turbine oil commands a higher price than an oil that emulsifies easily. The assumption has often been made, however, that oils that resist emulsification are also better for other uses; for instance, are superior lubricants for automotive equipment, such as motor cars and trucks. That this assumption is not necessarily true is shown by the present report.

Four pairs of oils, each pair made by a different refiner from California crude petroleum, were tested in an engine of a type commonly used for a motor-bus service. The test was severe, the engine running continuously for 8 hours at high speed under nearly full load. No oil was added during the test period. Consequently, if differences in the oils were of importance they should have caused varia-

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tions in the operation or in the mechanical condition of the engine or in the characteristics of the oils themselves after use.

One oil of each pair was nonemulsifying and had a low alkali-absorption number. The other oil of each pair emulsified readily and had a high alkali-absorption number. As shown in detail in the body of the report, each oil was analyzed both before and after use, and the results on engine conditions of the use of each oil were carefully studied. It was concluded that "Differences indicated by alkali-absorption numbers (and emulsion, demulsibility, and oxidation numbers) are without significance with regard to engine service."

This conclusion, especially if checked by other investigators working with other oils and different engines, is important as indicating that for use in automotive equipment oils need not be refined to as high a degree as for use in turbines and similar machinery. It indicates that savings may be made in present refining processes, and presents possibilities of successfully utilizing crude oils that to-day are not being refined to make lubricants.

One of the chief interests of the Bureau of Mines is the conservation and economic utilization of mineral products, including petroleum. The bureau is endeavoring to answer such questions as these:

1. Will the supply of lubricating oils be adequate if there should be a shortage of petroleum?

2. What are the effects of various refining methods on the characteristics of lubricating oils?

3. What types of lubricating oils can be made from so-called "fuel oil" crudes?

4. What types of lubricating oils can be made from other mineral sources, such as oil shale and coal tar?

The present report and its conclusions are a part of this general study. For the bureau's work a detailed study of what constitutes a good lubricating oil for each type of service is unnecessary. One oil that is known to be fairly satisfactory in automotive service has been adopted as a reference standard, and other oils are compared with this reference oil.

F. B. Tough,
Former Chief Petroleum Engineer, Bureau of Mines.

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By MARTIN J. GAVIN[1] and GUSTAV WADE[2]

INTRODUCTION

PURPOSE OF WORK

The investigation covered by this report was agreed upon by the American Petroleum Institute and the United States Bureau of Mines, March 5, 1923, and approved by the Secretary of the Interior, March 6, 1923. The purpose of the work, as stated in the cooperative agreement, was "to make engine tests to determine the relative merits of western oils[3] that do and do not pass the acidity and emulsion tests as set forth in Technical Paper 305,[4] Bureau of Mines, for class C oils."

ACKNOWLEDGMENTS

The work was done in the San Francisco laboratory of the Bureau of Mines. Participants for the American Petroleum Institute were members of the Pacific coast group of the advisory committee of that organization, as follows: S. E. Campbell, representing the Associated Oil Co.; W. H. Van Senden, representing the Shell Co. of California; J. B. Terry, representing the Standard Oil Co. of California; R. E. Haylett, representing the Union Oil Co. of California. The laboratory work was conducted by J. S. Desmond, E. C. Lane, Elmer Eitel, and the authors.

Acknowledgment is made to the United States Bureau of Standards for cooperation in planning the program of the investigation. Particular thanks are due W. S. James, former physicist of the Bureau of Standards, for many helpful suggestions and criticisms. Acknowledgment is due to N. A. C. Smith, petroleum chemist of the Bureau of Mines, for suggestions and criticisms during the conduct of the work and for aid in preparing this report; also to C. P. Bowie, engineer in charge of the San Francisco office of the bureau.

[1] Refinery engineer, U. S. Bureau of Mines.
[2] Dynamometer engineer, American Petroleum Institute.
[3] Lubricating oils manufactured from California crude petroleum by California refiners.
[4] Specifications for Petroleum Products Adopted by the Interdepartmental Petroleum Specifications Committee, Effective Jan. 23, 1922; Amended Mar. 1, 1922: Tech. Paper 305, Bureau of Mines, 1922, p. 14.

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EQUIPMENT AND APPARATUS

ENGINE AND DYNAMOMETER EQUIPMENT

Engine.—The engine used (fig. 1) was a modified Hall-Scott four-cylinder engine of the following general specifications: Bore, 4 inches; stroke, 5½ inches; compression ratio, 4.83 to 1.00.

Valves and valve timing.—Overhead valves in dome-type head. Valves actuated by overhead cam shaft operated by chain-belt-and-gear drive on front of engine.

Carburetor.—One and one-fourth-inch Zenith fixed jet, model L–6. Jet, 1.00 mm.; compensating jet, 1.10 mm.· idling well, 0.60 mm.; and Venturi, 26 mm.

Lubrication.—Full pressure, operated by a gear pump in front end of crank case. System supplies a constant stream of oil to valve mechanism on engine head, as well as to crank shaft and connecting-rod bearings. Return oil from head flows to crank case at front end of engine.

Ignition.—Magneto.

Spark Plugs.—A. C. plugs, situated just below intake valve.

Cooling.—Water circulated by centrifugal pump driven by extension of magneto shaft. In these tests the cooling water was circulated through a radiator submerged in a tank of water whose temperature was carefully regulated.

Gasoline supply.—Thirty-gallon tank supported on balance and feeding by gravity to carburetor.

ADDITIONAL EQUIPMENT FOR EXPERIMENTS

A thermometer in the intake-air line just ahead of the carburetor indicated the intake-air temperature. By adjustment of a slide covering the port in the air line from stove to carburetor, intake-air temperature could be held at the desired point. To assist in regulating intake-air temperature, an electric fan directing a stream of air to the air-intake port was used when necessary. A thermometer in the crank-case sump indicated the temperature of the crank-case oil, and whenever necessary this temperature was kept down by another electric fan blowing air on the crank case.

An orifice meter in the water-cooling system indicated the relative amounts of water circulated, and thermometers in the water inlet and outlet pipes indicated temperatures of incoming and outgoing water.

Pressure of oil in the circulating system was indicated by a pressure gauge of the usual type. Intake-manifold pressures were indicated by a mercury manometer (closed barometer type to indicate absolute pressure) connected with the intake manifold between carburetor and manifold branches.

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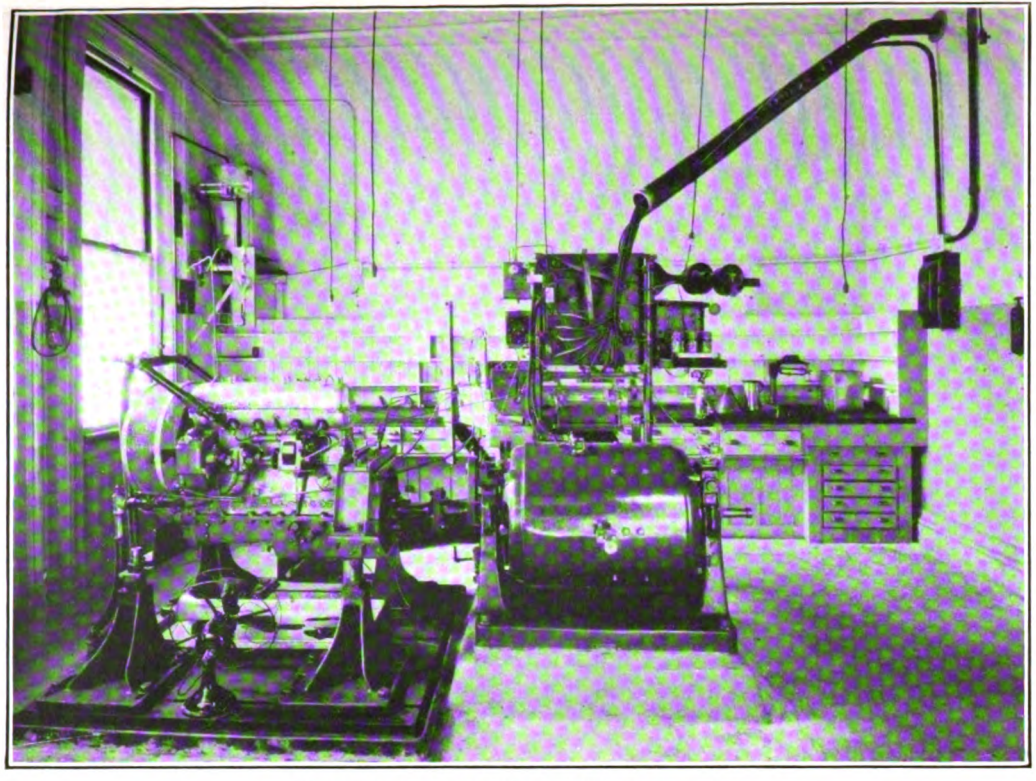

FIGURE 1.—Engine direct connected to dynamometer

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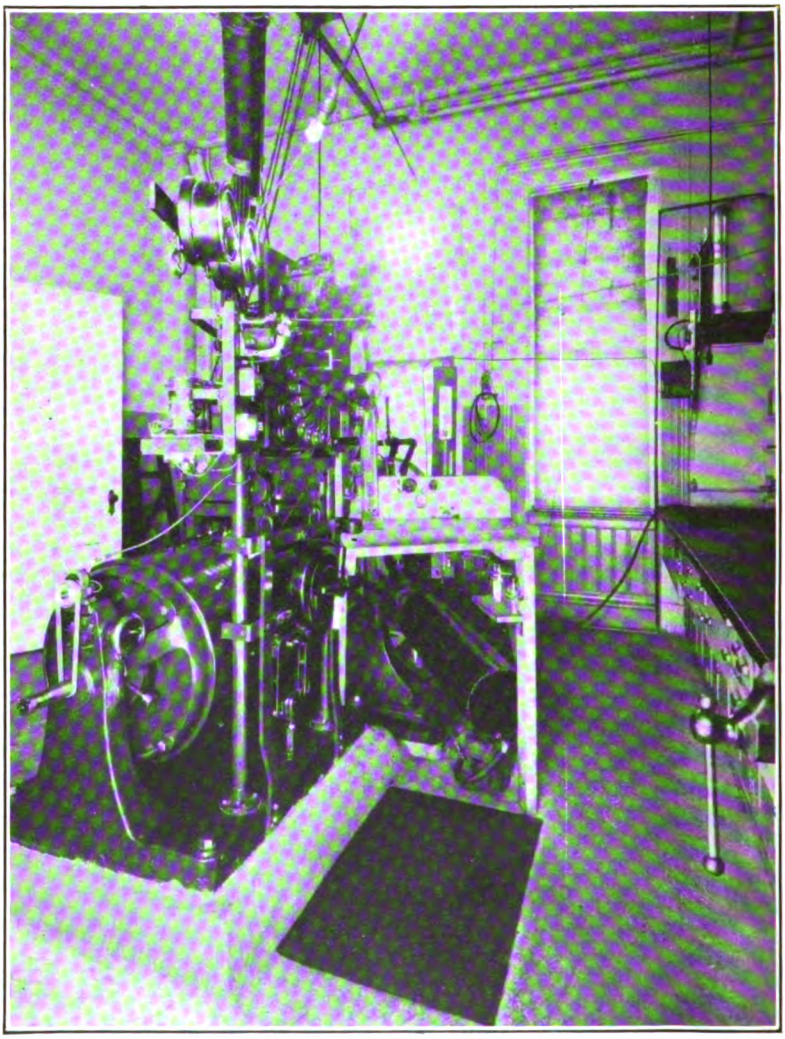

FIGURE 2.—Dynamometer and switchboard

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DYNAMOMETER

The engine was connected by a flexible coupling to a Sprague electric dynamometer, type T. L. C. 24 (fig. 2). This dynamometer permits direct weighing of torque and by a simple calculation the determination of horsepower output. Standard auxiliary equipment included an electric tachometer, a revolution counter, field and load rheostats and contactors, a device for metering gasoline, a voltmeter, and an ammeter.

CONDITIONS OF OPERATION OF ENGINE

After preliminary tests the conditions adopted for the engine service-tests of the oils were as follows:

1. Duration of test, 8 hours.
2. Speed, 1,600 revolutions per minute.
3. Load, 0.8 full throttle, as indicated by intake-manifold pressure.
4. Temperatures, sump oil, 185° F.; jacket water, constant at a value that would maintain 185° F., oil temperature; carburetor air, 150° F.
5. Fuel consumption, constant within ±2 per cent (approximately 0.60 pound per horsepower hour).
6. Fuel, same fuel (domestic aviation gasoline)[5] used throughout test; crankcase dilution not to exceed 1½ per cent as determined on final sample of used oil.

OILS USED IN TESTS

It was decided to limit the present investigation to oils similar in general character to oils of class A, medium grade, and class C, medium grade,[6] which differ mainly in emulsion and alkali-absorption[7] characteristics.

Each of the four cooperating companies furnished for the tests two medium-grade oils, one having an alkali-absorption number of 0.1 or less and emulsion characteristics which passed class C requirements,[8] the other having an alkali-absorption number as high as possible and emulsion characteristics which would not pass class C requirements. It was stipulated that the oils from any one company were to be made from the same crude and to be as nearly as possible identical in all respects except as to alkali-absorption numbers and emulsion characteristics. It is to be noted that none of the oils were necessarily to be commercial products, and any or all of them may have been made especially for this investigation.

[5] Technical Paper 305, Bureau of Mines, p. 3.
[6] Technical Paper 305, Bureau of Mines, pp. 12–13, and 14–16.
[7] In this report the expression "alkali-absorption" is used instead of the expression "acidity," since the so-called acidity of these oils is not corrosive. Alkali-absorption number is the weight in milligrams of KOH necessary to give a neutral indication with phenolphthalein to 1 gram of oil, when tested according to method 510.3 in Tech. Paper 208, Bureau of Mines, p. 47.
[8] The oil of low alkali-absorption number furnished by one company failed to pass the class C test with caustic soda.

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As practical limits of variance between the two oils furnished by any one company, the following tolerances were suggested:

Tolerances for properties of test oil

Property	Test method [1]	Tolerance	Property	Test method [1]	Tolerance
Viscosity at 100° F.	30.1	297 to 303 seconds.	Pour point	20.1	±10° F.
Flash point	110.3	±10° F.	Carbon residue	500.1	±0.10 per cent.
Fire point	110.3	Do.	Corrosion	530.3	None in either oil.

[1] Numbers under this heading refer to test methods so designated in Methods for Testing Petroleum Products, a Handbook for Testing Laboratories, Adopted by the Interdepartmental Petroleum Specifications Committee: Tech. Paper 298, Bureau of Mines, 1922, pp. 4, 7, 28, 47, 53.

In addition to these test oils, the committee furnished an ample supply of a "reference" oil, the properties of which were similar to those of the test oils. Before the oils were run in the engine their physical and chemical properties were determined in the laboratory of the Bureau of Mines and checked by the laboratories of at least two of the cooperating companies. The physical and chemical properties of the oils furnished for this investigation are tabulated in Tables 1 and 2, page 34. The result of check determinations on these oils is discussed under the heading "Results of tests by different laboratories." The designating letters of the oils are as follows:

Designations and types of oils

Oil	Type	Furnished by company
A-1	Class C (low alkali absorption)	A.
A-2	Class A (high alkali absorption)	A.
B-1	Class A (high alkali absorption)	B.
B-2	Class C (low alkali absorption)	B.
C-1	Class A (high alkali absorption)	C.
C-2	Class C (low alkali absorption)	C.
D-1	Class A (high alkali absorption)	D.
D-2	Class C (low alkali absorption)	D.
S-2	Class A (high alkali absorption)	Reference oil.

SEQUENCE OF TESTS

The oils were run in the engine in the following order:

Test series A:	Oil	Test series B:	Oil
Log No. 7	S-2	Log No. 13	[a] S-2
Log No. 8	A-1	Log No. 14	B-1
Log No. 9	A-2	Log No. 15	B-2
Log No. 10	S-2	Log No. 16	S-2
Log No. 11	A-2	Log No. 17	B-2
Log No. 12	A-1	Log No. 18	B-1
Log No. 13	S-2	Log No. 19 [b]	S-2

[a] Note that the last reference oil run in the previous series is also the first reference run in the following series.

[b] Valves ground and bearings taken up after this run.

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Test series C:	Oil
Log No. 20	S–2
Log No. 21	C–1
Log No. 22	C–2
Log No. 23	S–2
Log No. 24	C–2
Log No. 25	C–1
Log No. 26	S–2
Test series D:	
Log No. 26 [a]	S–2
Log No. 27	D–1
Log No. 29	D–2
Log No. 30	S–2
Log No. 31	D–2
Log No. 32	D–1
Log No. 33 [c]	S–2
Log No. 35	S–2
Log No. 36	S–2
Log No. 37	S–2
Log No. 38	S–2
Test series D (repeat)	
Log No. 39	S–2
Log No. 40	D–1
Log No. 41	D–2
Log No. 42	S–2
Test series D (repeat)—Con.	Oil
Log No. 43	D–2
Log No. 44	D–1
Log No. 45	S–2
Test series A (repeat):	
Log No. 45 [a]	S–2
Log No. 46	A–1
Log No. 47	A–2
Log No. 48	S–2
Log No. 49	A–2
Log No. 50	A–1
Log No. 51	S–2
Log No. 52	S–2
Log No. 53	B–2
Log No. 54 [d] (failure)	S–2
Log No. 55 (failure)	S–2
Log No. 56	S–2
Log No. 57 (failure)	S–2
Log No. 58 [e]	S–2
Log No. 59	S–2
Log No. 60	B–2
Log No. 61	S–2
Log No. 62	C–1
Log No. 63	S–2
Log No. 64	S–2

This sequence insured that each run on each test oil was immediately preceded or followed by a run on the reference oil, and thus furnished indication of the progress of engine wear and a means of correcting for it if necessary. The order of testing each pair of test oils tended to balance out differences due to changes in engine condition while each pair was being run, and increased the probable accuracy of average figures for each test oil. The tests of the D oils were repeated because the test results indicated that the engine was in poor condition when these oils were first run (see p. 9). The tests on the A oils were repeated in an effort to check back to the first tests of the complete series. Complete data on conditions and results of engine tests are tabulated in Tables 5A and 5B (pp. 36–39), and data on changes in physical and chemical properties of the oils are tabulated in Tables 10A and 10B (pp. 42–49). Data dealing with results of single tests and changes in particular properties are also presented in other tables and are discussed later.

METHODS OF SAMPLING AND TESTING

An accurately weighed amount (approximately 20 pounds) of oil was charged into the engine for each run. A sample of the unused oil was retained for testing and reference. During the run samples of

[a] Note that the best reference oil run in the previous series is also the first reference run in the following series.

[c] Overhaul after this run.

[d] New bearing.

[e] Last seven runs (logs 58–64) were to compare oil C–1 with oil B–2, which previously had given what seemed the poorest and the best service, respectively.

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oil of approximately 1¾ pounds were drawn from the oil-circulating system at the end of the first and fourth hours of the test. Just before the end of the run a small sample (75 c. c.) of oil was also taken from the circulating system to determine percentage of "insolubles." [9]

At the end of the run all fuel was drawn from the carburetor and supply line, and the friction torque of the engine with wide-open throttle was immediately determined by "motoring over" at 1,000 1,200, 1,400, and 1,600 revolutions per minute.

As soon as these friction tests had been made, the oil was drained from the crank case into a tared container, the oil-pan cover plates were removed, and as much as possible of the used oil was drained into the final sample, the quantity of which was accurately determined. The engine was allowed to drain into a tared oil pan over night, and these drainings were included in calculating the oil consumption.

The cylinder head was then removed and the carbon carefully scraped out and saved for examination. The pistons were also removed and the carbon was scraped from their lower surfaces and set aside for examination.

A sample of the gasoline used in each run was tested according to standard practice to insure uniformity of fuel. Carbon samples were washed with domestic aviation gasoline to remove oil, dried to constant weight at 105° C., and weighed. The carbon was then ashed and its content of metals determined.

The oil samples were tested in accordance with the schedule on the following page.

DISTILLATION TESTS OF NEW AND OF USED OILS

In addition to the above tests, samples of new and of final used oils were fractionally distilled under reduced pressure. Two methods of distillation were used—one was the standard method [10] used by the Bureau of Mines for examining lubricating oils, the other was fractionation into 10 per cent fractions at 10 mm. pressure.

In the first method 200 c. c. of the sample was distilled at a uniform rate in a glass flask at 40 mm. absolute pressure; one fraction was taken up to 392° F. vapor temperature, and subsequent fractions at every even rise of 45° F. in vapor temperature up to 572° F. The pressure was then reduced to 15 mm. absolute, and one additional fraction taken up to the same final temperature (572° F.). Volumes of the fractions, the specific gravities, and the viscosities were determined.

[9] Material insoluble in or precipitated by A. S. T. M. specification petroleum naphtha. This naphtha is specified in Tech. Paper 298, Bureau of Mines, p. 41.

[10] Dean, E. W., Hill, H. H., Smith, N. A. C., and Jacobs, W. A., The Analytical Distillation of Petroleum and Its Products: Bull. 207, Bureau of Mines, 1922, pp. 19–31 and 35–36.

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Schedule of tests of oil samples [1]

Test	New	1 hour	4 hours	Final	Test method [2]
Gravity	Yes	No	No	Yes	Hydrometer.
Color	Yes	No	No	No	Tag-Robinson colorimeter.
Viscosity: [3]					
100° F.	Yes	Yes	Yes	Yes	30. 1.
130° F.	Yes	No	No	Yes	30. 1.
185° F.	Yes	No	No	Yes	30. 1.
210° F.	Yes	No	No	Yes	30. 1.
Emulsion: [4]					
Distilled water	Yes	Yes (u)	Yes (u)	Yes (f and u)	320. 1.
Salt solution	Yes	(?)	(?)	(?)	320. 1.
Caustic soda	Yes	(?)	(?)	(?)	320. 1.
R. E. test	Yes	No	No	Yes (f and u)	A. S. T. M.
Demulsibility [5]	Yes	No	No	Yes (f and u)	320. 3.
Pour point	Yes	No	No	Yes (f and u)	20. 1.
Alkali-absorption number	Yes	Yes (u)	Yes (u)	Yes (u)	51. 03.
Corrosion	Yes	No	No	Yes (u)	530. 3.
Flash and fire points	Yes	Yes (u)	Yes (u)	Yes (u)	110. 3,
Dilution	Yes	No	No	Yes (u)	(6).
Carbon residue	Yes	Yes (f and u)	Yes (f and u)	Yes (f and u)	500. 1.
A. S. T. M. petroleum naphtha "insolubles", per cent by weight.	Yes [8]	Yes (u)	Yes (u)	Yes (u)	(7).
A. S. T. M. petroleum naphtha "insolubles," per cent by volume.	Yes	No	No	Yes (u)	(8).
Ash	Yes	No	No	Yes (u)	(9).
Oxidation	Yes	No	No	No	(10).

[1] (f) designates filtered and (u) unfiltered oil. The filter was two thicknesses of Whatman's No. 2 filter paper on a steam funnel.

[2] Test methods designated by numbers refer to methods so designated in Technical Paper 298, Bureau of Mines.

[3] Viscosities of samples from engine taken after filtering hot through a 200-mesh screen.

[4] The expression (?) indicates that the emulsion tests with salt solution and caustic soda were not to be made unless the sample passed the emulsion test with distilled water. (For a discussion of emulsion and demulsibility tests see p. 27.)

[5] Method for dilution experimentally worked out in the Bureau of Mines laboratory by a study of artificial mixtures. The method tends to yield results that are slightly high, but in no test did the dilution percentage of the final sample exceed 1 per cent.

[6] None of the new oils contained material insoluble in A. S. T. M. specification naphtha.

[7] Ten grams of well-mixed sample taken as soon as possible after withdrawal from engine, diluted with 100 c. c. A. S. T. M. specification petroleum naphtha, stored in dark, cool place for 24 hours, filtered through asbestos pad on Gooch crucible, and dried at 105° C. to constant weight. Duplicates were always run and good checks were obtained.

[8] Fifty cubic centimeters, well mixed sample, diluted to 100 c. c. with A. S. T. M. specification petroleum naphtha, and whirled in centrifuge at 1,600 revolutions per minute to constant volume of sediment.

[9] Fifty grams of oil ashed.

[10] Modification of hot-plate air-bath method developed by Shell Co. of California. Excellent check results were obtained with new oils by different operators using the same apparatus, but no satisfactory method of determining the oxidation values of used oils was developed.

In the second method 2 liters of the sample were distilled in a copper flask at 10 mm. absolute pressure; 10 per cent fractions were taken and a 10 per cent residue was left in the still. Temperatures of vapor and liquid during the distillation and at cut points were recorded. The vapor temperatures were unreliable, probably on account of the foaming of the liquid in the still, but the liquid temperatures checked satisfactorily. Volumes, gravities, and viscosities of the fractions were determined. The significant data of these distillations are presented in Tables 3 and 4 (pp. 34–35).

CONDITIONING OF ENGINE BEFORE TEST RUNS

After the used oil had been completely removed from the engine and the carbon scraped out at the end of each test, the inside of the crank case was cleaned as thoroughly as possible and the main and

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connecting rod bearings were inspected. The crank case, pistons, and engine head were then replaced, the crank case filled with the new oil to be used in the next test, and the engine run under its own power for about 15 minutes. The flushing oil was then removed, and the rinsing process repeated with new oil by "motoring-over" the warm engine with the dynamometer until assurance was had that the crank case and oil passages were free from contamination by the old oil. The cylinder head was then removed and the oil wiped from piston heads and combustion chambers. The cylinder head was replaced, and after valve timing, valve-tappet clearances, spark plugs, distributor, breaker points, oil-pan gaskets, and test apparatus were inspected, the set-up was ready for the next run.

DISCUSSION OF DATA ON TEST RUNS

It is to be noted again that the purpose of the investigation was to determine by engine tests the "relative merits of western oils[11]" of low and high alkali-absorption numbers and weak and strong emulsifying properties. In other words, the problem was to determine whether relatively poor service correlates with relatively high alkali-absorption numbers and strong emulsion-forming properties. In this investigation an attempt was made to determine relative service values of the two oils of each of the four test pairs by consideration of the following factors.

1. Effect of the oil on the engine.—Engine wear as indicated by inspection and by amounts of ash and of metals in used oil and in engine carbon.

2. Effectiveness of lubrication as shown by power output of engine, in distinction to effectiveness as shown by engine wear.

3. Effect of the engine test on the oils. (a) Change of viscosity, (b) increase of carbon residue, (c) formation of A. S. T. M. specification naphtha "insolubles," and (d) deposition of carbon in the engine.

4. Consumption of oil during standard test run.

PRESENTATION OF DATA ON TEST RUNS

Tables 1 and 2 show the physical and chemical properties of the new oils used in the tests. Table 3 shows the boiling point, flash point, increase of viscosity in service, and vacuum distillation data for the new oils, and the general relationships that hold between those factors. They are discussed later in detail. Table 3 should be examined in conjunction with Table 4, which gives gravities and viscosities of the first and last 10 per cent fractions of the test oils obtained by distillation at 10 mm. absolute pressure.

[11] Internal-combustion engine lubricating oils made from California crude petroleum by California refiners.

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Tables 5A and 5B give essential data of engine operating conditions during the test runs. Table 5A gives data in the order of testing and Table 5B for each test oil.[12] It will be noted that after log 35 the differences between the temperatures of the incoming and the outgoing cooling water are less than before. This change followed the overhaul of the engine, which included the fitting of new rings, and is evidence that the ring clearances were greater than before. Other information indicates that the rings fitted during the overhaul were of poorer quality than those originally in the engine. After the overhaul the series of runs on the A and D oils were repeated. Obviously the repeat runs were made under conditions different from those of the first runs. Actual experimental data for the two series of runs of these oils may thus be expected to differ. Therefore, although all the results of the tests can not be considered as absolute measurements, they serve to indicate the practical service values of the oils; at least, the results for each series of runs are comparable among themselves.

Tables 6, 7, 8, and 9 give arranged average figures from Table 5A. Table 6 shows actual oil consumption for each run, average consumption for each oil in each series of runs, and the same averages corrected on the basis of changes in average consumption of the reference oil from series to series. Table 7 gives the same figures for torque, Table 8 for horsepower, and Table 9 for temperature factor.[13] The corrected averages are not used in making comparisons between the two oils of any given test pair but indicate the results of changes in engine conditions during the whole series of runs. The corrected averages also indicate approximately what the consumption of oil and the torque developed with each oil would have been had the mechanical condition of the engine remained constant during the whole series of runs.

Tables 10A and 10B include tabulation of data relative to properties of new oils, changes in these properties as a result of use, deposition of carbon in the engine, and oil consumption. In Table 10A these data are shown in the order of running the engine tests and in Table 10B they are arranged for each oil.

Tables 11, 12, 13, 14, 15, 16, 17, and 18 are derived from Table 10A. In Table 11 the viscosity changes of each oil in each series are tabulated, averaged, and corrected. In Table 12 data on formation of "insolubles" are arranged in the same way. Table 13 shows oil consumption, percentage of "insolubles," and temperature factors for each test. Table 14 gives the weights of "insolubles" formed per pound of oil consumed for each test; these weights are averaged and

[12] For a discussion of figures in the last column of these tables, "Temperature factor," see p. 28.
[13] See p. 28.

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arranged for comparison in Table 15. Table 16 gives data on increase of carbon residue in the oils and average increases for each oil in each series. Table 17 gives a similar tabulation of weights of

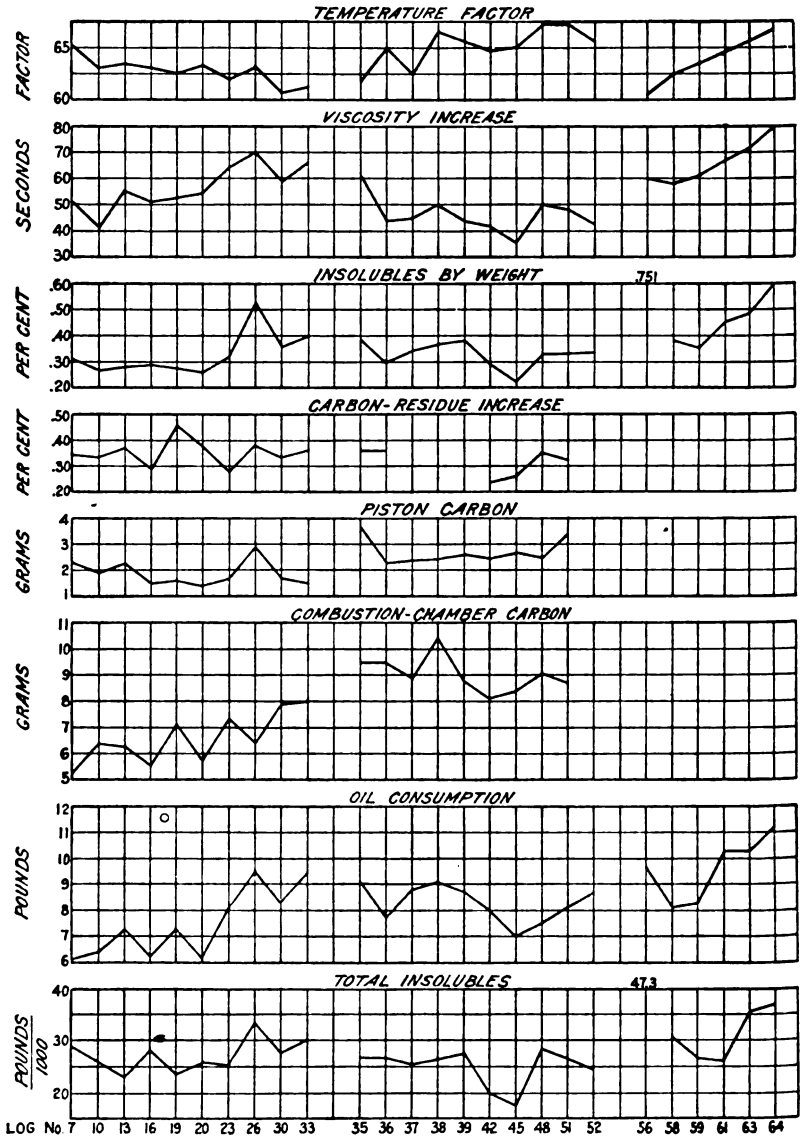

FIGURE 4.—Data on runs with reference oil, S 2

carbon deposited on the lower surfaces of the pistons, and Table 18 of carbon deposited in the combustion chamber.

Figure 3 shows graphically the pertinent data for all the tests of the complete series of runs, and Figure 4 shows similar data for the sequence

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of runs with the reference oils. Other tables and figures developed from the data are discussed in proper order.

COMPARISONS AND RELATIONSHIPS

Relationship or lack of relationship in the comparative service values of two oils of a given pair is shown by differences in the numerical values of the properties of the oils, by changes in these properties, and by differences in the behavior of the engine. It was thought that these differences could be emphasized by tabulating the ratios of their numerical values. Table 19 shows both the differences and the calculated ratios. Each ratio is calculated by dividing the numerical value of one property of an oil with a high alkali-absorption number by the numerical value of the same property of the oil of low alkali-absorption number of the same pair. Data in Table 19 are taken from Tables 2 and 3. An example of the calculation of the ratios in Table 19 follows:

Alkali-absorption number, oil C–1 = 0.60
Alkali-absorption number, oil C–2 = .04
Ratio alkali-absorption numbers $\frac{\text{C–1}}{\text{C–2}} = \frac{0.60}{0.04} = 15.0$

Table 20 gives data similarly obtained in the tests of the oils, using averages for the two runs on the same oil in each test series. An example of the calculation of ratios in Table 20 follows:

Viscosity increase, oil A–2 = 72 seconds.
Viscosity increase, oil A–1 = 51 seconds.
Ratio viscosity increase $\frac{\text{A–2}}{\text{A–1}} = \frac{72}{51} = 1.41$.

In order to compare the behavior of the two oils of a series with the behavior of the reference oil during the same test series, differences and ratios that show the maximum variation of results of runs on the reference oil for each test series have been calculated and are shown in Table 21. The method of calculating the ratios was as follows:

Reference-oil runs in test series B.
Maximum weight of piston carbon 2.27 grams (log 13).
Minimum weight of piston carbon 1.52 grams (log 16).
Ratio of maximum difference $\frac{2.27}{1.52} = 1.49$

Because differences and ratios for the test oils are based on averages of the two runs in each test series, it is better to compare them with averages of the related runs with the reference oil. In Table 22, therefore, differences and ratios of the average results of the first and last runs and the result of the second run, respectively, of the reference oil in each series have been tabulated.

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An example of the calculation of ratios of the average results of runs with reference oil, as given in Table 22, appear below:

Test series D. Reference-oil runs are logs 26, 30, and 33. Percentages of insolubles formed in these runs are 0.523, 0.358, and 0. 400, respectively.

Ratio of averages calculated below.

$$\frac{\text{Insolubles log 30}}{\frac{\text{Insolubles log 26}+\text{insolubles log 33}}{2}}=\frac{0.358}{\frac{0.523+0.400}{2}}=\frac{0.358}{0.461}=0.777$$

In Table 23 all the differences and ratios shown in Tables 19, 20, 21, and 22 have been brought together to facilitate comparison. Table 23 is arranged to show differences and ratios of average results of the two runs on the test oils in each series and the differences and ratios of maximum and minimum results for the runs on reference oil that are related to each series. It also shows differences and ratios of average results of runs with the reference oil in each series as given in Table 22.

In these tables (19 to 23) differences and ratios have been based on averages of the results of the two runs with each test oil in each series. As has been noted, the sequence of runs was so planned that averages of data for two runs on the same oil would tend to minimize changes in the condition of the engine while the oils were being run and between runs. Average figures thus probably represent more accurately the service value of an oil than do data for successive single runs with two oils. However, such data for successive single runs have been calculated and are shown graphically in Figures 5, 6, and 7. To facilitate plotting these figures, differences are shown as percentages rather than as ratios. These figures also show differences for the runs with reference oil that precede and follow the runs with the test oils.

COMPARISONS OF RELATIVE SERVICE VALUE

EFFECT OF OILS ON ENGINE

Engine wear as indicated by inspection and by the amounts of ash and of metals in the used oil and in the engine carbon.—Inspection of the engine after each run did not indicate that either oil of a given pair was responsible for more wear than the other oil. Differences in engine wear in any one run were too small to be evident, although a gradual progressive wear during the entire series of runs was noticeable. In log 21, the first run on oil C–1, a wrist pin apparently became slightly overheated and in log 31, the second run on oil D–2, a wrist pin was badly burned and consumption of oil was unusually high. Later runs after the engine had been overhauled showed that the trouble indicated in these two runs was caused by the relatively poor mechanical condition of the engine (worn rings, etc.) resulting

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from normal wear. Figure 4, which shows data for the successive runs with the reference oil, contains no evidence that the engine was worn more by the oils of high alkali-absorption number than by those of low alkali-absorption number.

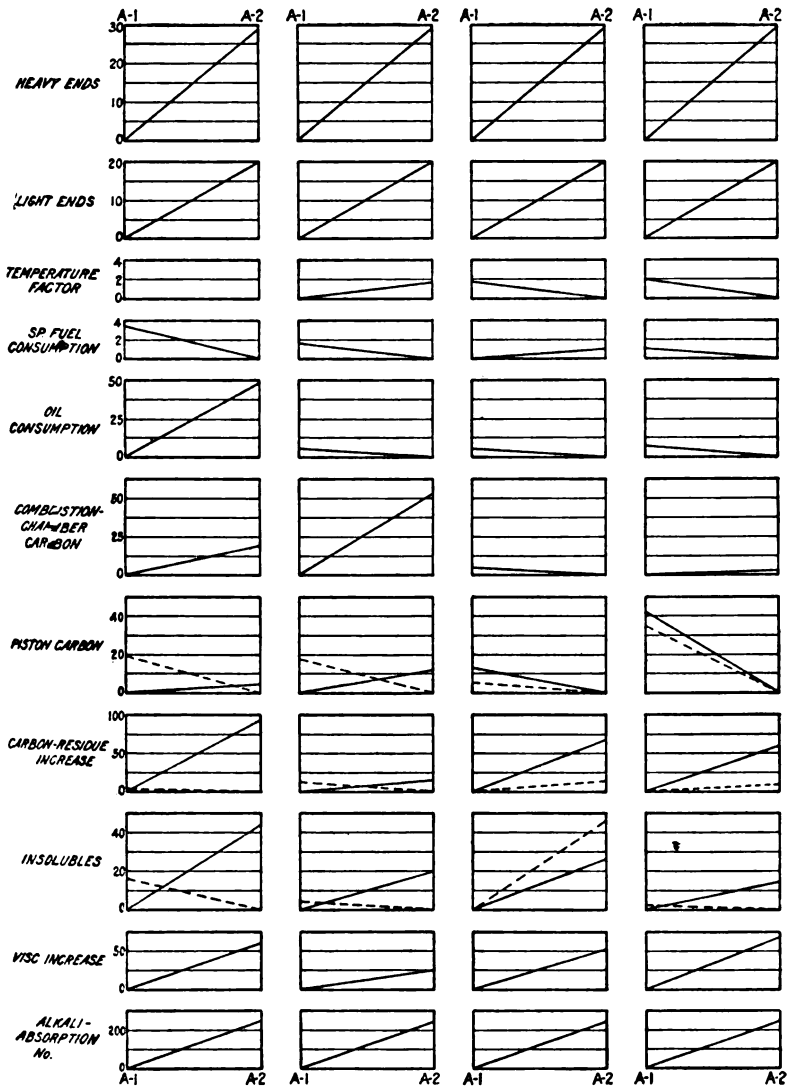

FIGURE 5.—Comparisons of individual runs, A oils
Broken lines refer to related reference-oil runs

The ash and metals determined in the used oils and in the carbon samples were practically uniform throughout the runs, although in a few tests the results were erratic. High and low results were obtained for oils of both high and low alkali-absorption numbers, and

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no correlation could be shown between percentages of ash and metal and the alkali-absorption numbers and emulsifying properties of the oils.

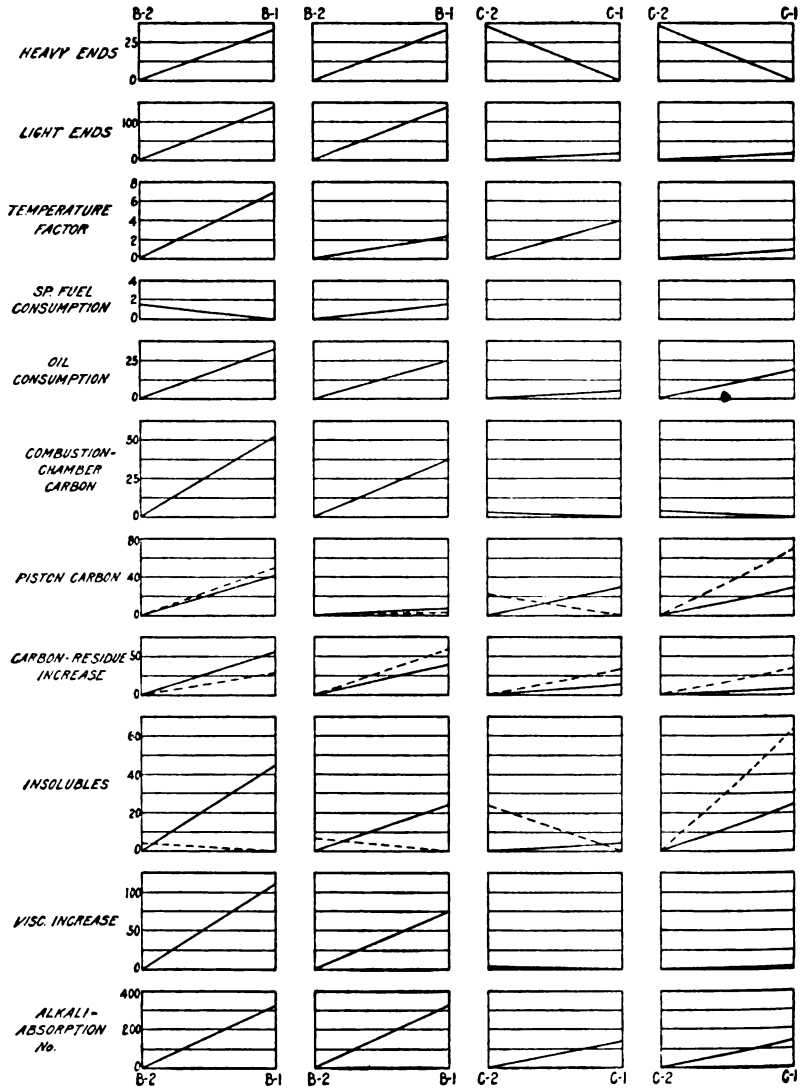

FIGURE 6.—Comparisons of individual runs, B and C oils
Broken lines refer to related reference-oil runs

Examination of the data which might show the effect of the oils on the engine indicate that, of the test oils used, oils of high alkali-absorption number do not cause more engine wear than oils of low alkali-absorption number.

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POWER OUTPUT OF ENGINE AS DIFFERENTIATED FROM EFFECTIVENESS OF LUBRICATION SHOWN BY ENGINE WEAR

Attention is called to the curve for brake horsepower in Figure 3. The average power output of successive runs with the reference oil gradually drops from a high maximum on the first run (log 7) to a

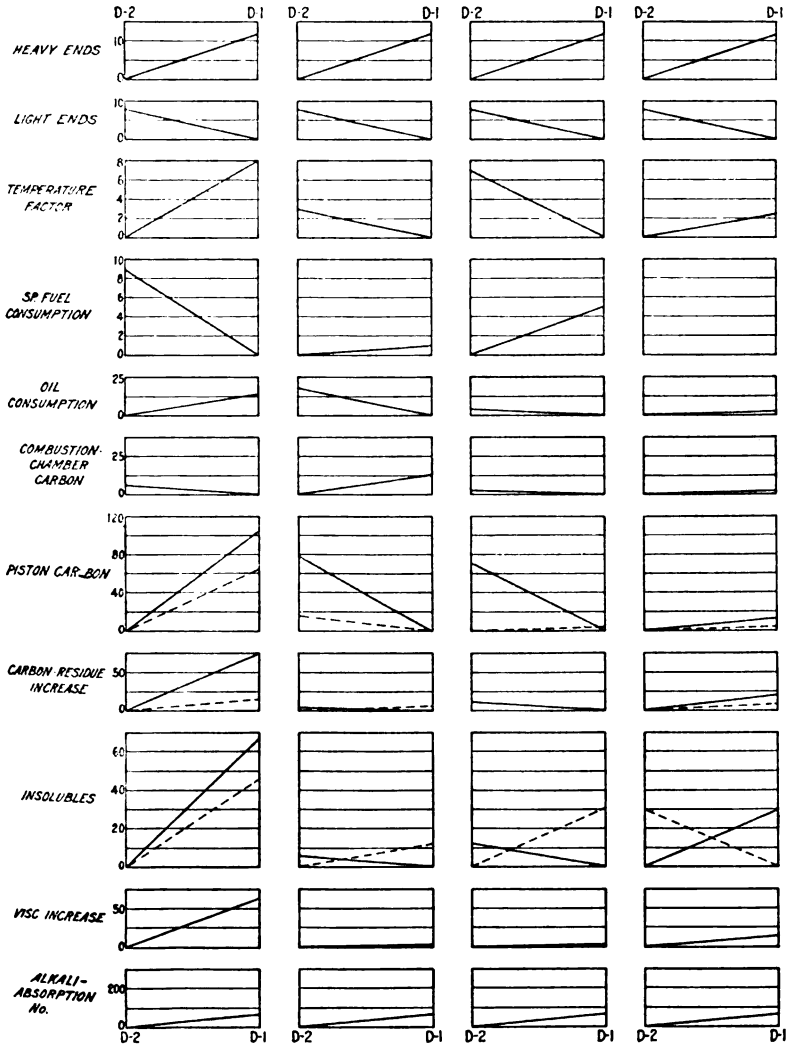

FIGURE 7.—Comparisons of individual runs, D oils
Broken lines refer to related reference-oil runs

minimum on the run prior to the engine overhaul (log 33), and after the running-in period (logs 35 to 39, inclusive) it rises to the end of the series. The horsepower developed with the reference oil (circled dots, fig. 3) is reasonably uniform and shows the expected result of

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normal engine wear. Table 8, which gives data of horsepower developed, does not show consistent relationships between power development and the alkali-absorption numbers of the test oils, nor do the differences and ratios in Table 23 show any consistent relationship between these factors. Table 7, which gives torque data, shows that if there is any relationship between effectiveness of lubrication (as shown by power output) and alkali-absorption numbers of the oils, the power data obtained in this work are not sufficiently precise to indicate it.

EFFECT OF ENGINE TEST ON THE OILS

Change of viscosity.—Tables 11 and 23 and Figures 3, 4, and 5 show that viscosities of the oils of high alkali-absorption numbers of the A, B, and D series increase in service more than those of the respective oils of low alkali-absorption numbers. In the first runs with the C oils the viscosity of the oil of low alkali-absorption number (C–2) increased more than that of the oil of high alkali-absorption number (C–1); whereas in the second runs with these oils the increase was practically the same for both oils, and the differences between the two oils were less than the differences between averages of related runs for the reference oil. Therefore it does not seem possible to attribute differences in increase of viscosity to differences of alkali-absorption numbers.

Table 23 and Figure 8 show that differences in viscosity increase can be correlated with differences in the volatilities of the oils as indicated by the relative amounts of low-boiling and high-boiling fractions in the oils. This is shown by the table below.

Averages of viscosity increase and volatility of oils tested, taken from Table 23

Oils	Viscosity increase (seconds)				Heavy ends (per cent)		Light ends (per cent)		Alkali-absorption number	
	Test oils		Reference oil							
	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference
B-1 / B-2	1.89	25	0.95	−1.5	1.33	1.9	2.39	3.9	33.3	0.97
A-2	1.41	21	.77	−12.0						
A-1	[1] 1.57	28	[1] 1.19	8.0	1.29	2.7	1.21	1.8	25.2	.49
D-1	1.27	14	.86	−9.0						
D-2	[1] 1.07	3	1.04	1.5	1.14	1.0	.92	−.6	7.2	.31
C-1 / C-2	.98	−2	1.03	2.0	.80	−2.2	1.18	2.0	15.0	.56

[1] Repeat series.

When individual runs are considered, the correlation between heavy ends and high viscosity increase holds nearly as well as in the foregoing relationships calculated from averages. Figures 5, 6, and 7

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show that in 11 of the 12 runs with oils with relatively large amounts of high-boiling fractions the viscosity increase is greater than for the corresponding runs with oils with smaller amounts of high-boiling fractions. The one failure of the relationship is in the second runs with oils C–1 and C–2, and the difference in viscosity change here amounts to only one second. Evidently a high increase of viscosity can not be attributed to a high alkali-absorption number of an oil.

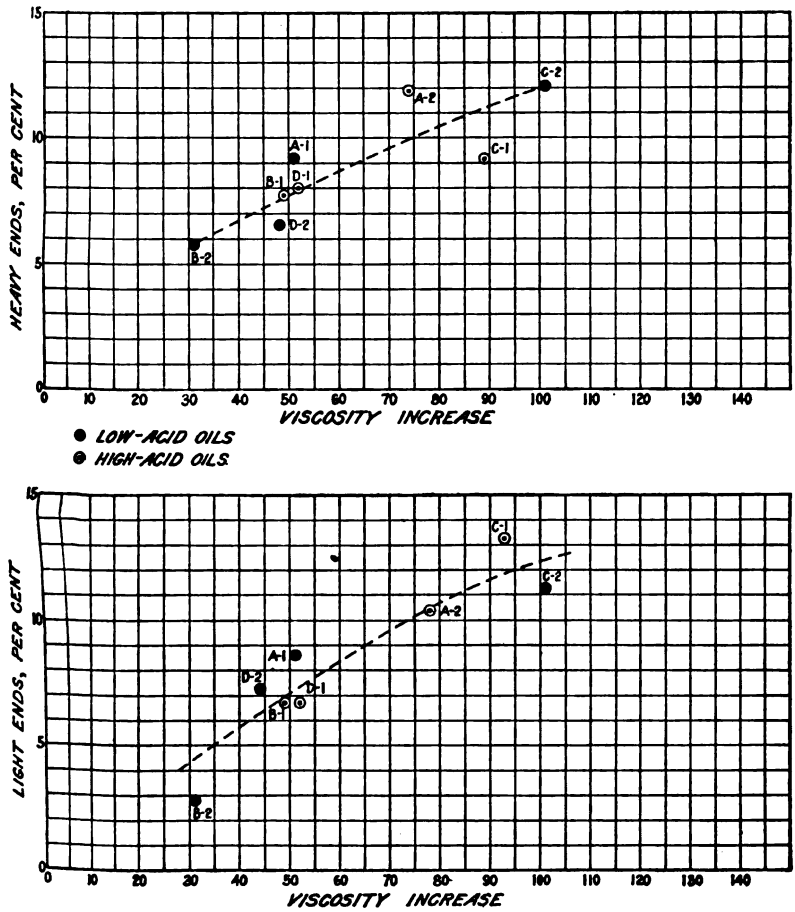

FIGURE 8.—Relationship between volatility and increase in viscosity

Increase of carbon residue.—Averages of figures giving increase of carbon residue as the result of use (Table 16) show that for each pair of oils tested the oil with the higher alkali-absorption number gives the greater increase of carbon residue, with the exception of the repeat series of runs with oils D–1 and D–2, whose average increases are the same.

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Averages for alkali-absorption numbers and carbon-residue increases for oils tested, taken from Table 23

Oils	Alkali-absorption number		Carbon-residue increase					
			Test oils		Reference oils			
					Average		Maximum	
	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio
B-1 / B-2	0.97	33.3	0.14	1.48	−0.13	0.70	0.17	1.59
A-2 / A-1	.49	25.5	.13 [1] .14	1.50 [1] 1.61	−.03 .06	.93 1.21	.04 .09	1.12 1.35
C-1 / C-2	.56	15.0	.04	1.10	−.10	.74	.10	1.36
D-1 / D-2	.31	7.2	.07 .00	1.20 [1] 1.00	−.04 −.02	.89 .92	.05 .02	1.15 1.08

[1] Repeat of series.

The tabulation of averages taken from Table 23 shows an apparent relationship between alkali-absorption numbers and carbon-residue increase. It also shows that, except for the A oils and the first run of the D oils, the differences in the carbon-residue increases for the reference-oil runs in related series were greater than the average differences between the test oils. Oil A–2 seems definitely to show a greater increase of carbon residue than oil A–1, but other than this differences of carbon-residue increase between oils of low and high alkali-absorption numbers are of the same order as differences in carbon-residue increase between related runs on the reference oil. These relationships are brought out graphically in Figures 5, 6, and 7.

It should be noted in comparing the increase of carbon residue that to average the results gives the figures a somewhat false significance. For example, with the C oils, oil C–2, low alkali-absorption number (log 24) shows virtually the same carbon-residue increase as oil C–1, high alkali-absorption number (log 25); with the D oils, oil D–2, low alkali-absorption number (log 31) shows a higher carbon-residue increase than oil D–1, high alkali-absorption number (log 32); and in the repeat series with the D oils, oil D–2 (log 41), shows a greater carbon-residue increase than oil D–1 (log 40).

Evidently, therefore, though Tables 13 and 23 indicate that the oils of low alkali-absorption numbers show generally a smaller increase of carbon residue than the oils of high alkali-absorption numbers, the differences are within the experimental errors of the engine test and the method of determining carbon residue, with the possible exception of oils A–2 and A–1.

Formation of insolubles.—Table 12 shows the percentages by weight of A. S. T. M. specification naphtha insolubles [14] formed in the oils in the engine tests. Tables 14 and 15 show the total weights of insolubles formed and the weights of insolubles formed per pound of oil consumed. It is to be noted that all of the new oils were free from insolubles. The "insoluble" compounds probably are results of

[14] The word "insolubles" in this report refers to the material (in the oil) insoluble in or precipitated by A. S. T. M. specification naphtha.

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polymerization and oxidation reactions and are more or less soluble in the oils in which they form. For the oils tested in this work about half the insolubles is actually sediment that will not pass a single thickness of filter paper and might therefore plug oil passages in the engine if enough was present.

Tables 12 and 14 show that in each series the oils of high alkali-absorption numbers formed a greater total weight of insolubles than those of low alkali-absorption numbers, and that the used oils from the tests with oils of high alkali-absorption numbers contain a greater percentage by weight of insolubles than do those with oils of low alkali-absorption numbers. Data for the individual runs in Table 12 and in Figures 5, 6, and 7 show only two failures in the apparent relationship between high alkali-absorption number of the new oil and high percentage of insolubles in the used oil; both were in the series of runs with oils D–1 and D–2, one failure being in log 31 (D–2) in which a wrist pin was burned. Table 14 also shows only two failures in the apparent relationship between high alkali-absorption numbers of the new oils and total weight of insolubles formed during the test run—one failure in the runs with the C oils and the other in the repeat runs with the D oils. This apparent relationship, however, is due to the coincidence that most of the oils of high alkali-absorption numbers contained more volatile material than those of low alkali-absorption numbers.

Table 23 shows a similar correlation between alkali-absorption number and percentage of insolubles in the used oil, but it also shows (with the exception of the first series of runs with oils A–1 and A–2 and the runs with oils B–1 and B–2) that maximum and average differences of percentages and total weight of insolubles in the used reference oils in related series are virtually the same as, or greater than, differences for oils of high and low alkali-absorption numbers in the same series. The differences and ratios are shown below.

Average and maximum differences and ratios for alkali-absorption numbers and percentages and total weights of insolubles formed in test and in reference oils

Oils	Alkali absorption		Percentage A. S. T. M. specification naphtha insolubles						Total weights of A. S. T. M. specification naphtha insolubles (grams)					
			Test oils (average)		Reference oil				Test oils (average)		Reference oil			
					Maximum		Average				Maximum		Average	
	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio
A-2 / A-1	0.49	25.5	0.071	1.31	0.043	1.16	−0.026	0.91	3.8	1.16	5.5	1.24	−0.2	0.99
B-1 / B-2	.97	33.3	.078	1.34	.019	1.07	.015	1.05	1.6	1.07	4.7	1.20	4.5	1.19
C-1 / C-2	.56	15.0	.075	1.16	.260	1.99	−.070	.82	2.3	1.07	12.0	1.56	−2.6	.85
D-1 / D-2	.31	7.2	.073	1.22	.165	1.46	−.103	.78	8.2	1.40	5.9	1.21	−4.2	.87
D-1[1] / D-2	.31	7.2	.024	1.09	.156	1.70	−.012	.96	2.0	1.10	10.1	1.58	−2.4	.89
A-2[1] / A-1	.49	25.5	.048	1.16	.107	1.48	.052	1.19	4.7	1.22	10.9	1.63	6.3	1.26

[1] Repeat runs after overhaul.

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Differences between insolubles (both percentages and total weights) in the used oils from the runs with the oils of high and low alkali-absorption numbers are thus of the same order as differences between insolubles in the used reference oils in related tests.

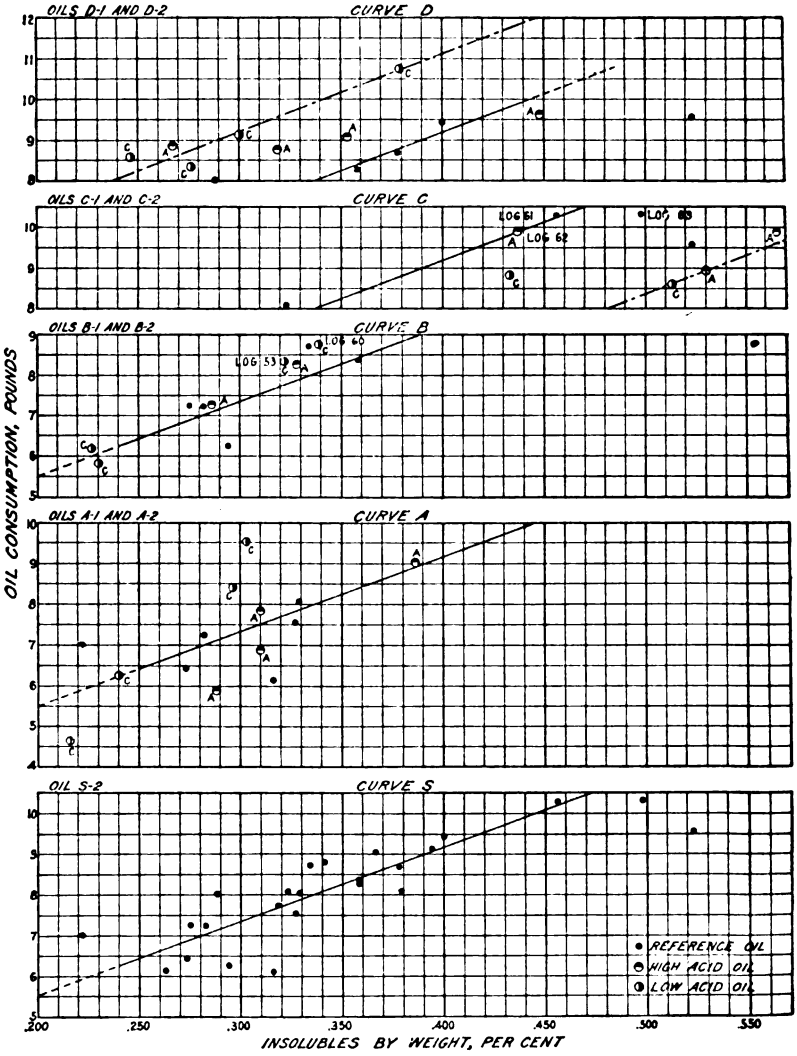

FIGURE 9.—Relationship between insolubles and oil consumption

There is, moreover, a relationship between consumption of oil and percentage of insolubles in the used oils (Table 13). This relationship is also shown graphically in the curves of Figure 9.[15]

[15] Table 13 also indicates the influence of the so-called temperature factor. It is probable that the plotted points of the curves in Figure 9 would lie even more closely to the average curve if they could be corrected for the influence of combustion chamber and piston temperatures, the variations of which may be roughly indicated by the temperature factor. (See p. 28.)

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Curve S, Figure 9, oil S–2.—Curve *S* of Figure 9 shows the unmistakable relationship between consumption of oil and percentage of insolubles in the used oil for the reference-oil runs. Curves *A*, *B*, *C*, and *D* show the same relationship for the A, B, C, and D oils, respectively. The straight lines drawn in these curves have the slope of the average curve for the reference oil (curve *S*) and are placed in the same position the average curve occupies in curve *S*. Also for oils C and D the average curve is shifted horizontally (without changing its slope) to bring it into line with the plotted points for the test oils.

Curve A, Figure 9, oils A–1 and A–2.—Note that with the used oils the general relationship of oil consumption and percentage of insolubles that holds for the reference oil also holds for the A oils. The oil of low alkali-absorption number is better, and the oil of high alkali-absorption number is poorer than the average for the reference oil in three of four tests. Note also that one run with the reference oil is nearly as much better than the average for the reference oil as is the best run of the oil of low alkali-absorption number; that one run with the reference oil is poorer than any run with the oil of high alkali-absorption number; and that the divergence of the reference oil runs from the average curve is as great as the divergence between the oils of low and high alkali-absorption numbers.

Curve B, Figure 9, oils B–1 and B–2.—Note that all the points for the oils of high and low alkali-absorption numbers fall remarkably close to a line whose slope is the same as the average for the reference oils, and that the divergence of the reference oils from the average curve is greater than is that of the oils of high and low alkali-absorption numbers of the B series. Note that the run with oil B–2 (low alkali-absorption number) in log 60, at the end of the series, falls virtually on the line established in the earlier runs and in the normal relation between consumption and percentage of insolubles that seems to hold for all the oils. Note also that oils B–1, S–2, and B–2 were furnished by one company and represent an extreme range of alkali-absorption numbers, 1.00, 0.30, 0.03, respectively.

Curve C, Figure 9, oils C–1 and C–2.—Note that the oils of high and low alkali-absorption numbers in this series are poorer than the reference oil, but that three of the runs (two with oil of high and one with oil of low alkali-absorption number) fall on a line whose slope is that of the reference-oil curve.

One run with the oil of low alkali-absorption number (C–2) gave a much lower percentage of insolubles-consumption ratio than the others of this series, but in log 62 (at the end of the complete series) oil C–1 (high alkali-absorption number) gave a value as good as the best run with the oil of low alkali-absorption number (C–2) and nearly on the reference oil curve.

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Curve D, Figure 9, oils D–1 and D–2.—Note that all but one run with the D oils are better than the average for the reference oil. One run with the oil of high alkali-absorption number (D–1) is very poor, and one is practically as good as the best for the oil of low alkali-absorption number (D–2). All but two points fall close to a line whose slope is that of the reference oil, and their divergence is not as great as one run with the reference oil in the same series.

Relation of consumption of oil to formation of insolubles.—It is not particularly remarkable that for the reference oil the percentage of insolubles in the used oil is a function of oil consumption. The fact that the same relationship holds for the test oils indicates, however, that formation of insolubles is not a function of alkali-absorption numbers. Percentage of insolubles in the used oil is a function of both the actual insolubles formed and the amount of oil consumed, as with a high consumption the insolubles would be concentrated in the residual used oil.

Tables 14 and 15 show the actual weights of insolubles formed per pound of oil consumed. The averages of Table 15 show that for the first three series of runs the oils of low alkali-absorption numbers formed more insolubles per pound of oil consumed than the corresponding oils of high alkali-absorption numbers, whereas in the last three series the relationship is reversed.

The conclusion drawn from Tables 13, 14, and 15 and Figure 9 is that, within the experimental errors of engine operation and of sampling and of determination of insolubles, the formation of insolubles is a function of the consumption of oil, influenced probably by the temperatures within the engine. Consumption of oil, as is shown below, is not a function of the alkali-absorption numbers of the oils tested. The amount of insolubles formed by these oils is therefore not a function of their alkali-absorption numbers.

Attention is called to the fact that in no run was a large amount of insolubles formed. The extreme case was in log 56 for the reference oil, just after a new bearing had been fitted; then the total weight of insolubles formed amounted to 0.047 pound, or about two-thirds of an ounce. The greatest amount of insolubles formed while the engine was in normal condition was in log 21, oil C–1. In this run the weight of insolubles formed was 0.037 pound. Note that in this run over 40 per cent of the oil charged to the engine was consumed during the engine test.

Deposition of carbon in the engine.—*Piston carbon.*—Figures given in Table 17 for weights of carbon deposited under the piston are apparently erratic, but none were higher than could be expected. In Table 23 the reader should note that differences in weights of piston-

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carbon deposits can not be correlated with differences in alkali-absorption numbers or in emulsifying properties of the oils. He should also note that the weights of piston carbon formed in the reference-oil runs are apparently as erratic as those formed by the test oils.[16]

Combustion-chamber carbon.—Deposition of combustion-chamber carbon can not be correlated with alkali-absorption numbers or emulsifying properties of the oils. The differences and ratios of averages in Table 23 show that high combustion-chamber carbon accompanies high alkali-absorption number in only three of the six series of test runs. It will be observed that the variation in amount of combustion-chamber carbon deposited by the reference oils in related runs is about the same as for that deposited by the test oils. Table 18 likewise shows failure of correlation. Tables 18 and 23, however, give some indication that formation of combustion-chamber carbon is influenced by combustion-chamber temperatures and by viscosities of the oils in the engine. It is to be noted that the weights of carbon deposited in the combustion chamber by the test oils are not high.

CONSUMPTION OF OIL DURING STANDARD TEST RUN

Attention is called to Figure 4, which gives the oil consumption for successive runs with the reference oil. The figure shows that the consumption of the reference oil was between 6 and 11.2 pounds. It shows a generally progressive increase from the start of the test series until the engine was overhauled (log 33); a decrease from a high point during the running-in period (logs 35 to 39, inclusive); then a further decrease to a low point (log 45); and another increase to the end of the series. In general, then, the consumption of oil follows what seems to be normal engine wear, though there are eccentricities that in part only can be correlated with "temperature factor."[17]

It is questionable whether the consumption data are precise enough to serve as a basis of discussion; evidently some unknown variable, engine or test, influences the consumption of oil. In Table 23, however, averages for the test oils indicate that the relative consumption of two oils of a pair is influenced, on this engine and with this system of lubrication, by the relative amounts of low-boiling fractions in the oils. The following data, taken from Table 23, show this relationship and also that differences in alkali-absorption numbers of the oils do not correlate with differences in consumption.

[16] See p. 29 for an indicated relationship between deposit of piston carbon and the so-called temperature factor.

[17] See p. 28 for discussion of temperature factor.

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Differences and ratios for pairs of test oils for alkali-absorption numbers, oil consumption, and low-boiling fractions

Oils	Alkali-absorption numbers		Oil consumption (pounds)		Low-boiling fractions (per cent)	
	Difference	Ratio	Difference	Ratio	Difference	Ratio
A-2 / A-1	0.49	25.5	0.94	1.17	1.8	1.21
B-1 / B-2	.97	33.3	1.78	1.30	3.9	2.39
C-1 / C-2	.56	15.0	.95	1.11	2.0	1.18
D-1 / D-2	.31	7.2	−.22	.98	−.6	.92
D-1 [1] / D-2	.31	7.2	−.05	.99	−.6	.92
A-2 [1] / A-1	.49	25.5	−.54	.94	1.8	1.21

[1] Rerun of series after engine overhaul.

Figures 5, 6, and 7, which give relationships for individual runs rather than averages, show that high alkali-absorption numbers correlate with high consumption of oil in 7 of 12 runs with oils of high alkali-absorption numbers, and that high consumption of oil correlates with low alkali-absorption numbers in 5 of 12 runs with oils of low alkali-absorption numbers. High consumption of oil correlates with relatively high percentage of low-boiling fractions seven out of twelve times, and in four of the five runs where this relationship fails the failure correlates with a relatively high temperature factor.[18] If any relationship exists between the alkali-absorption numbers of the oils and amount of oil consumed, this work was not precise enough to reveal it.

SUMMARY

A lubricating oil for an internal-combustion engine can be considered as giving good service if (*a*) it lubricates effectively, (*b*) with its use there is minimum danger of lubrication failure, and (*c*) its consumption is not excessive

1. All of the oils used in these tests seem to lubricate effectively. The oils of high alkali-absorption numbers seem to have lubricated as effectively as those of low alkali-absorption numbers. The test conditions were much more severe than the average conditions of practical service, yet no differences in lubricating efficiency were detectable.

2. In one run of the complete series a wrist pin in the engine was badly burned, and in another (near the end of the series) a crank bearing broke. Neither mishap can be attributed to properties of the oils. The fact that there were only two mechanical failures in the whole series of rigorous service tests shows the good performance of the oils and the engine.

[18] See p. 29.

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3. The figures for oil consumption may not be precise enough to justify conclusions, but the data do not indicate that the oils of high alkali-absorption numbers were consumed at a greater rate than those of low alkali-absorption numbers.

4. Increase of viscosity of the oils during use, although possibly an important factor, is evidently a function of the volatility of an oil and is not related to its alkali-absorption number.

5. For the oils tested, formation of insolubles is seemingly not related to alkali-absorption number but is related to oil consumption.

6. Increase of carbon residue can hardly be correlated with lubricating efficiency or failure. The evidence in Table 16 seems to favor the oils of low alkali-absorption numbers, but such evidence is within the experimental error of the determination of carbon residue. If, regardless of this fact, the data are taken to indicate superiority of the oils of low alkali-absorption numbers, the differences shown in these tests are evidently too small to be of importance in commercial practice.

7. The consumption of none of the oils was excessive except in parts of the series where normal engine wear (piston rings) showed appreciable effects. Everything else being equal, a low consumption of oil is most desirable. It is evident that further work can be done to obtain more consistent figures on oil consumption and at the same time on power output.

8. Experience gained in these tests indicates the possibility of eliminating or reducing the range of certain variables. Future work may lead to the development of a standardized engine test which will be capable of giving reproducible results as to consumption of oil and development of power.

CONCLUSION

For the oils tested [19] it is concluded that differences indicated by alkali-absorption numbers (and emulsion, demulsibility, and oxidation numbers) are without significance with regard to engine service.

RESULTS OF TESTS OF OILS BY DIFFERENT LABORATORIES

Samples of one of the test oils (B–1) were sent for testing to eight different laboratories—three in the eastern part of the country and five in California. Table A gives the reports of these laboratories.

Samples of the reference oil and the test oils were sent to two laboratories in California for test and were also tested in the laboratory of the Bureau of Mines. Table B gives the reports on these oils.

[19] Internal-combustion engine lubricating-oils made by California refiners from California crude petroleum.

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DISCUSSION OF TABLE A—TESTS WITH OIL B-1

Generally good agreement between the results of tests of different laboratories is noted.

1. Gravity determinations agree as well as can be expected.

2. Color determinations of the oil range from 3 to 4−; four of the laboratories reported the N. P. A. color as 3 or 3+, one as 3½+, one as 3¾+, and one as 4−. Only three laboratories report color, Robinson, and they agree fairly well.

3. Reported viscosity at 100° F. ranges from 296 to 310 seconds. Five of the laboratories, however, report viscosity within ±1 per cent of 303 seconds, which is the average of all the determinations. At 130° F. the reported viscosity ranges from 125 to 133 seconds; the average is 130 seconds, which is reported by one laboratory. None of the other laboratories is within ±1 per cent of this. At 175° F. the reported viscosity ranges from 58 to 62.5 seconds. The average is 60.4. Two of the six laboratories reporting come within ±1 per cent of the average. At 210° F. the reported viscosity ranges from 45 to 48 seconds. The average is 46.4. Four of the seven laboratories reporting come within ±1 per cent of the average.

4. Seven laboratories report on the emulsion test with distilled water, salt solution, and caustic soda. Some of the laboratories do not state whether the sample passes the test but give the volumes of water, oil, and emulsion, and the general appearance of the emulsion. The data are interpreted to mean that all the laboratories consider that the sample passed the test with distilled water and salt solution. With caustic soda, however, the data from six laboratories show that the sample failed to pass the test, and one laboratory reports the emulsion test with caustic soda as satisfactory.

5. R. E. number is in fair agreement, ranging from 1.5 to 3.0.

6. All the laboratories report pour test at or below 0° F.

7. Alkali-absorption number is in fair agreement, the reported values ranging from 0.95 to 1.15. The average is 1.047. All the numbers reported are within ±10 per cent of the average.

8. Seven of the laboratories report corrosion as satisfactory. The other noted that the copper was very slightly discolored.

9. The agreement between the reports on demulsibility value is extremely poor. The demulsibility figures range from 135 to 960. Three laboratories of the eight reporting indicate a demulsibility of more than 300, the others, less than 300.

10. The flash point reported ranges from 355 to 370° F., an extreme range of 15° F., which is considered reasonably good agreement.

11. The fire point reported ranges from 410 to 415° F., except that one laboratory reports 430° F. Except for this one result the agreement is excellent.

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12. Carbon residue reported ranges from 0.04 to 1.10 per cent, and except for two laboratories the results range from 0.08 to 0.10 per cent—excellent agreement for a sample low in carbon residue.

DISCUSSION OF TABLE B—TESTS WITH REFERENCE AND TEST OILS

In Table B the reported results are generally in good agreement. The following examples of poor agreement are noted.

1. R.E. number of oil C–2: Two laboratories report this number as 1.0 and 1.33, respectively, but the third assigns it a somewhat indefinite value somewhere between 7 and 11.

2. Demulsibilities: Except for oils C–1 and D–1, both with low demulsibilities, the results of the demulsibility tests by the different laboratories are in extremely poor agreement. As an extreme example, oil B–1 is cited (see also Table A). For the same oil three laboratories report the demulsibility as 480, 840, and 270, respectively. (In Table A the values 960, 135, 173, 420, 272, 200, 480, and 250 are given for another sample of this oil.) For oil A–1 three laboratories report the demulsibility as 360, 460, and 1,620, respectively.

3. Alkali-absorption numbers: Results with the oils of low alkali absorption are in fairly good agreement. With the oils of high alkali absorption the agreement is not generally so good.

4. Carbon residue: Results are only in fair agreement; laboratory B generally reported a lower figure than the others and laboratory A a higher figure.

RETENTION OF EMULSION-RESISTING PROPERTIES AND LOW ALKALI-ABSORPTION NUMBERS OF OILS DURING ENGINE SERVICE

Regardless of the emulsifying properties of the unused oils, after the oils had been run in the engine for an hour they all failed to pass the emulsion test with caustic soda and all had a very low demulsibility.

A series of successive emulsion tests was made during one run with oil B–2, which before use passed all the emulsion tests and had a demulsibility of 1,620. After 30 minutes use in the engine the oil would no longer pass the emulsion test with caustic soda, and its demulsibility had dropped to 135.

Table 10A shows that in some runs of oils of initial low alkali absorption after 4 hours' use in the engine the alkali-absorption number had increased to more than 0.30. In every run of oils of initial low alkali absorption after 8 hours, use the alkali absorption number had increased to more than 0.30 (usually it was much higher). The table also shows that in most of the series of runs the alkali-

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absorption number of the oil of low alkali absorption increased at a greater rate than that of the corresponding oil of high alkali absorption.

TEMPERATURE FACTOR

When results of the experimental work were being correlated, it became evident that some uncontrolled factor or factors had influenced the results. It was appreciated that although many unknown or unrecognized factors might have important bearing on the results, the temperature of the combustion chambers and pistons of the engine possibly was of greatest importance. Data taken during the runs furnished no means of determining or calculating these temperatures, but attempts were made to calculate factors which might indicate approximately the relative temperatures for the different runs.

The "temperature factors" shown in Tables 5A, 5B, 9, and 13 were obtained by "cut and try" methods. Factors that might be expected to influence or indicate the temperatures of the combustion chamber and piston were multiplied, divided, added, and subtracted, until a set of figures was obtained which seemed to correlate with certain results of the tests of the reference oil. These figures, the so-called temperature factors of this report, were obtained for each run by multiplying the average horsepower developed during the run by the average jacket-water temperature for the run. There is little scientific basis for factors so derived; the only excuses for using them are that they represent an attempt to indicate the influence of an important variable and they seem to correlate certain results which otherwise seem erratic. That such unscientifically determined factors do correlate certain engine-test results indicates the need of accurate control and determination of engine temperatures in work of this nature.

TEMPERATURE FACTOR AND PISTON CARBON

Examination of Figures 3 and 4 (pp. 8 and 10) shows a general correlation between weights of piston carbon and "temperature factor." This relationship shows better for the test oils in Figure 3 than for the successive runs with the reference oil in Figure 4. Note in Figure 4 that logs 35 to 39, inclusive, followed complete overhauling of the engine and were in the nature of a "run-in." Note also that differences in weight of deposits of piston carbon can be correlated roughly with differences of temperature factors for the test oils of different series and fairly well for the averages of the runs with reference oil, as follows:

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Relation between differences of weight of piston carbon and difference in "temperature factor" for test oils

Oils	Difference in weights of piston carbon (gram)	Difference in "temperature factor"	Oils	Difference in weights of piston carbon (gram)	Difference in "temperature factor"
A-2 / A-1	0.06	0.39	D-1 / D-2	.13	1.54
S-2	−.35	−1.25	S-2	−.44	−1.45
B-1 / B-2	.34	3.73	D-1 / D-2 (repeat)	−.52	−1.45
S-2	−.41	−.06	S-2	.12	−.60
C-1 / C-2	.58	1.59	A-2 / A-1 (repeat)	−.56	−1.20
S-2	−.42	−1.37	S-2	−.53	1.08

The correlation is not quite so good when individual runs rather than averages are compared, as indicated by Figures 5, 6, and 7. The ratios shown by these figures indicate that of 12 runs with oils of high alkali-absorption numbers 8 gave more piston carbon than the 8 corresponding runs with oils of low alkali-absorption numbers. High temperature factor corresponds with high piston carbon in 9 of the 12 runs with oils of high alkali-absorption numbers. Oils of low alkali-absorption numbers deposited more piston carbon than their corresponding oils of high alkali absorption-numbers in 4 out of 12 runs, in 3 of which the temperature factor was high for the oils of low alkali-absorption numbers. Of the 12 pairs of runs with the reference oil, high "temperature factor" accompanies high piston carbon seven times; in 2 runs temperature factors for both were the same, though piston carbon differed. In 3 pairs of runs, low "temperature factor" accompanied high piston carbon.

TEMPERATURE FACTOR AND CONSUMPTION OF OIL

As has been noted on page 24, relatively high consumption of oil correlates with relatively high percentage of low-boiling fractions in the test oils in 7 of the 12 runs with the oils of relatively high percentage of low-boiling fractions. In 4 of the 5 runs where this relationship fails the failure correlates with a relatively high temperature factor. Thus, 11 of the 12 cases of relatively high consumption of oil can be explained either by the volatility of the oils or by the temperature of the engine.

OTHER POSSIBLE INFLUENCES OF TEMPERATURE FACTOR

In Tables 13, 21, 22, and 23 are some indications that temperature factor influences the formation of insolubles, either directly or through its influence on the consumption of oil. This relationship seems to apply particularly to the runs with the reference oil. The possible influences are merely mentioned here, however, as the so-called temperature factor at best only roughly indicates what a similar factor calculated from adequate data might show.

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SPECIFICATIONS AND TESTING METHODS FOLLOWED

When the present investigation was being outlined, the Federal specifications for petroleum products and the methods of testing had been published by the Bureau of Mines as Technical Paper 305 [20] and Technical Paper 298.[21]

Accordingly, all references in this report to Federal specifications and testing methods are to those two technical papers. Both of them, however, are now out of print, as they were superseded by two later publications.[22]

The specifications mentioned in the present report have been changed only in minor details since the work started. The methods of testing have been changed somewhat, but the changes only tend to make the methods more definite, so that for the purpose of the present investigation reference may be made to any of the technical papers mentioned. Page references to corresponding specifications and methods appear in the following table:

Page references (in technical papers of Bureau of Mines) for specifications and methods of testing

Specification	Technical Paper		
	305	323	323A
Aviation gasoline domestic grade	3	2	2
Lubricants:			
Class A	12	11	9
Class C	14	13	12

Test method	Federal No.	A. S. T. M. No.	Technical paper		
			298	323	323A
Color by Saybolt chromometer	10.1		3	31	
Do	10.11	D156-23T			30
Color by Union colorimeter	10.2	D155-23T			33
Cloud and pour points	20.1	D97-21T	4		
Do	20.11	D97-22T		32	36
Viscosity of lubricating oils	30.1	D47-21	7		
Do	30.11	D47-22		36	
Viscosity	30.4	D88-23T			39
Distillation of gasoline	100.1	D86-21T	13		
Do	100.11			43	
Do	100.12				46
Open-cup flash and fire test	110.3	D92-21T	28	58	
Do	110.31	D92-23T			61
Precipitation number	310.1	D91-21T	40	70	73
Emulsion test at 130° F	320.1		42	72	
Do	320.11				75
Emulsion test at 180° F	320.2		43	73	
Do	320.21				76
Demulsibility at 130° F	320.3		43	73	
Do	320.31				76
Demulsibility at 180° F	320.4		44	74	
Do	320.41				77
Carbon residue	500.1	D47-21	46	76	
Do	500.11				79
Reaction test	510.1		47	77	80
Acidity in gasoline	510.2		47	78	80

[20] Technical Paper 305, Specifications for Petroleum Products Adopted by the Interdepartmental Petroleum Specifications Committee, Effective Jan. 23, 1922; Amended Mar. 1, 1922: 1922, 40 pp.

[21] Technical Paper 298, Methods for Testing Petroleum Products, a Handbook for Testing Laboratories, Adopted by the Interdepartmental Petroleum Specifications Committee: 1922, 58 pp.

[22] Technical Paper 323, Specifications for Petroleum Products and Methods for Testing, Federal Specifications Board, Standard Specification No. 2, 1924, 88 pp. Technical Paper 323A, United States Government Specification for Lubricants and Liquid Fuels and Methods for Testing, Federal Specifications Board, Standard Specification No. 2c, 1924, 89 pp.

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Page references (in technical papers of Bureau of Mines) for specifications and methods of testing—Continued

Test method	Federal No.	A. S. T. M. No.	Technical Paper		
			298	323	323A
Free acid	510.3	D47-21	47	78	80
Sulphur in burning oils	520.1	D90-21T	48	78	81
Doctor test	520.3		52	83	85
Corrosion test (copper dish)	530.1		53	83	86
Corrosion test at 212° F	530.3		53	84	
Do	530.31				87
Saponification number	540.1	D94-21T	54	85	87
Fatty oil	540.2		55	86	88
Unsaturation in gasoline	550.1		55	86	

TABLE A.—*Comparative tests of oil B–1 used in dynamometer tests*

Laboratory	1	2	3	4
Gravity, °A. P. I.	19.5	19.5	19.4	19.5
Specific gravity	0.937	0.937	0.938	0.937
Color, N. P. A.	3	3+	3½+	4—
Color, Robinson	9½	(1)	(1)	9
Viscosity:				
100° F.	304	301	310	303
130° F.	133	133	125	128
175° F.	62	59	58	62.5
210° F.	46	47	45	46
Emulsion:				
130° F. H_2O	(1)	39 c. c. clear water; 41 c. c. turbid oil.	O. K.	Passes.
1 per cent NaCl	(1)	do	do	Do.
1N NaOH	100 per cent	3 c. c. slightly cloudy; 2 c. c. turbid; 75 c. c. emulsion.	do	Does not pass.
R. E. number	2.5	2.0	(2)	3.0
Pour, °F.	−5	−10	−0	<0
Alkali-absorption, mg. KOH per gram.	1.15	1.03	1.04	1.116
Corrosion	O. K.	None	O. K.	Passes.
Demulsibility, 130° F.	960	135	173	420
Flash, °F.	355	365	360	365
Fire, °F.	415	415	410	430
Ash, per cent	None	None	None	0.0037
Carbon residue, per cent	0.04	0.10	0.088	0.08

Laboratory	5	6	7	8
Gravity, °A. P. I.	19.4	19.35	19.5	19.3
Specific gravity	0.9377	0.937	0.937	(1)
Color, N. P. A.	3+	(1)	3+	3¾
Color, Robinson	(1)	(1)	9¼	(1)
Viscosity:				
100° F.	296	308	302	305.5
130° F.	128	(1)	130	132.5
175° F.	60	(1)	(2)	61.0
210° F.	48	(1)	46	46.5
Emulsion:				
130° F. H_2O	11 minutes, O. K.	(1)	41 c. c. oil; drops oil to wall; 40 c. c. clear water.	42 c. c. oil; 38 c. c. water; slight cuff.[3]
1 per cent NaCl	13 minutes, O. K.	(1)	42 c. c. slightly turbid oil; 39 c. c. clear solution.	42 c. c. oil; 38 c. c. solution; slight cuff.[3]
1N NaOH	3 c. c. clear solution; 77 c. c. emulsion.	(1)	12 c. c. clear oil; 31 c. c. emulsion; 39 c. c. solution.	30 c. c. oil,[4] 23 c. c. emulsion; 27 c. c. solution.
R. E. number	(1)	(1)	1.5	3.0
Pour, °F.	0	<0		−15
Alkali-absorption, mg. KOH per gram.	1.95	1.02	1.00	1.071
Corrosion	O. K.	(1)	O. K.	Copper very slightly discolored.
Demulsibility, 130° F.	{200 / 272}	200	480	250
Flash, °F.	365	365	370	360
Fire, °F.	415	410	415	410
Ash, per cent	0.007	(1)	None	0.0054
Carbon residue, per cent	0.10	0.06	0.095	0.098

[1] Not reported. [2] Not determined. [3] 15 minutes. [4] 1 hour.

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TABLE B.—*Comparative laboratory tests of reference and test oils used in service runs*

Property	Oil S-2: Laboratory—				Oil A-1: Laboratory—			Oil A-2: Laboratory—		
	A	B	C	D	A	B	C	A	B	C
Specific gravity	0.9375				0.9287			0.9317		
Gravity, ° A. P. I.	19.4	19.5	19.4	19.4	20.8	20.8	20.8	20.4	20.4	20.5
Color, Robinson	9	9			16¼	13½		2	2¼+	
Color, N. P. A	3½	3½	4	3½-4	1½+	2	2	6	6	6+
Viscosity:										
100° F	302	303	304	299	293	291	289	297	298	293
130° F	130	131	131	129	127	129	128	129	131	129
185° F	55	55	56	56	55.6	55	56	56.2	55	56
210° F	46.6	46	46	46	46.4	46	48	46.5	46	48
Emulsion:										
H_2O	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	N. g.	N. g.	N. g.
NaCl	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	N. g.	N. g.	N. g.
NaOH	N. g.	N. g.	N. g.	N. g.	O. K.	O. K.	O. K.	N. g.	N. g.	N. g.
R. E. number	2.0	3.0	2.5		1.5	1.5	1.0	7.0	8.0	3.0
Demulsibility, 130° F.	223	172	207	1,620	460	360	1,620	120	61	162
Pour, ° F	−10	−5	0	−0	−10	−5	0−	0	−5	0−
Alkali absorption, mg. KOH per gram	0.30	0.37	0.33	0.28	0.02	0.03	0.025	0.51	0.75	0.57
Corrosion	O. K.	O. K.	None.	O. K.	O. K.	O. K.	None.	O. K.	O. K.	None.
Flash, ° F	370	365	365	360	365	355	360	355	355	355+
Fire, ° F	410	420	405	415	410	410	405	405	410	395+
Carbon residue, per cent	0.10	0.07	0.06	0.06	0.10	0.02	0.04	0.11	0.02	0.08
Ash, per cent	Nil.	0	0.0015	None.	Nil.	Nil.	0.0025	0.010	0	0.003

Property	Oil B-1: Laboratory—			Oil B-2: Laboratory—		
	A	B	C	A	B	C
Specific gravity	0.9372			0.9385		
Gravity, °A. P. I.	19.5	19.5	19.6	19.7	19.8	19.7
Color, Robinson	9¼	9½		9½	9¼+	
Color, N. P. A	3+	3½	3½+	3	3½	3½+
Viscosity:						
100° F	302	303	305	307	306	306
130° F	130	132	130	130	132	133
185° F	56	55	56	56	56	56
210° F	46.4	46	46	46.8	46	46
Emulsion:						
H_2O	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
NaCl	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
NaOH	N. g.	N. g.	N. g.	O. K.	O. K.	O. K.
R. E. number	1.5+	1.5	1.5	1.0	1.5	0.5
Demusibility, 130° F	480	840	270	1,620	480	1,440
Pour °F	−5	−5	0−	−5	0	0−
Alkali absorption, mg. KOH per gram	1.00	1.12	1.07	0.03	0.04	0.03
Corrosion	O. K.	O. K.	None.	O. K.	O. K.	None.
Flash, °F	370	365	370	365	360	[illegible]
Fire, °F	415	420	415	420	[illegible]	410
Carbon residue, per cent	0.10	0.04	0.09	0.05	0.06	0.08
Ash, per cent	Nil.	Nil.	0.004	None.	None.	0.002

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TABLE B.—*Comparative laboratory tests of reference and test oils used in service runs*—Continued

Property	Oil C-1: Laboratory—			Oil C-2: Laboratory—		
	A	B	C	A	B	C
Specific gravity	0.9372			0.9367		
Gravity, °A. P. I.	19.5	19.5	19.4	19.6	19.5	19.6
Color, Robinson	3+	3+		5¾	5¾	
Color, N. P. A.	5	5	5	4½	4½	4½
Viscosity:						
100° F.	338	338	336	334	337	336
130° F.	139	139	141	138	139	141
185° F.	57	57	57	57	57	57
210° F.	47.6	46	48	47.3	47	48
Emulsion:						
H_2O	N. g.	N. g.	N. g.	O. K.	O. K.	O. K.
NaCl	N. g.	N. g.	N. g.	O. K.	O. K.	O. K.
NaOH	N. g.	N. g.	N. g.	O. K.	O. K.	O. K.
R. E. number	17.5	16.5	20+	7–11	1.0	1.33
Demulsibility, 130° F.	22	27	0	405	1,620	184
Pour, °F.	0	0	0−	0	0	0−
Alkali absorption, mg. KOH per gram	0.60	0.79	0.60	0.04	0.03	0.035
Corrosion	O. K.	O. K.	None.	O. K.	O. K.	O. K.
Flash, °F.	340	335	335	340+	335	340
Fire, °F.	400	385	390	395	385	385
Carbon residue, per cent	0.15	0.11	0.13	0.10	0.11	0.11
Ash, per cent	0.015	0	0.025	Nil.	None.	<0.001

Property	Oil D-1: Laboratory—			Oil D-2: Laboratory—		
	A	B	C	A	B	C
Specific gravity	0.9340			0.9320		
Gravity, °A. P. I.	20.0	20.0	20.0	20.3	20.3	20.3
Color, Robinson	9¼	9½		10½	10−	
Color, N. P. A.	3+	3½	3+	2¾	3	3−
Viscosity:						
100° F.	302	300	305	297	302	296
130° F.	129	130	131	127	130	128
185° F.	56	55	57	55	55	56
210° F.	46.6	47	48	46.2	46	48
Emulsion:						
H_2O	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
NaCl	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
NaOH	N. g.	N. g.	N. g.	N. g.	N. g.	N. g.
R. E. number	2¼	2	2+	1.75	1	1½+
Demulsibility, 130° F.	240	250	270	500	1,620	1,620
Pour, °F.	−5	−5	0−	−5	−5	0−
Alkali absorption, mg. KOH per gram	0.36	0.41	0.20	0.05	0.10	None.
Corrosion	O. K.	O. K.	None.	O. K.	O. K.	None.
Flash, °F.	345	345	343	350	345	343
Fire, °F.	410	405	395	410	405	395
Carbon residue, per cent	0.07	0.04	0.06	0.09	0.05	0.09
Ash, per cent	Nil.	None.	<0.002	None.	None.	<0.002

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TABLE 1.—*Comparative tests of unused lubricating oils*

Property	Oil S-2	Oil A-1	Oil A-2	Oil B-1	Oil B-2	Oil C-1	Oil C-2	Oil D-1	Oil D-2
Specific gravity	0.9375	0.9287	0.9317	0.9372	0.9358	0.9372	0.9367	0.9340	0.9320
Gravity, °A. P. I.	19.4	20.8	20.4	19.5	19.7	19.5	19.6	20.0	20.3
Color, Robinson	9	16¼	2	9¼	9½	3+	5¾	9¼−	10½
Color, N. P. A.	3½	1¼+	6	3+	3	5	4½	3+	2¾
Viscosity:									
100° F.	302	293	297.0	301.8	306.6	338.2	334.0	302.4	296.7
130° F.	129.5	126.5	129	129.8	129.8	138.8	138.3	128.8	127.3
185° F.	56	55.6	56.2	55.7	56.0	57.2	57.4	55.6	55.2
210° F.	46.6	46.4	46.5	46.4	46.8	47.6	47.3	46.6	46.2
Emulsion:									
H_2O	O. K.	O. K.	(1)	O. K.	O. K.	(1)	O. K.	O. K.	O. K.
NaCl	O. K.	O. K.	(1)	O. K.	O. K.	(1)	O. K.	O. K.	O. K.
NaOH, per cent	91.3	O. K.	87.5	51.5	O. K.	56.2	O. K.	52.5	27.5
R. E. number	2.0	1.5	7.0	1.5+	1.0	17.5	[2] 7–11	2¼	1.75
Demulsibility, 130° F.	223	460	120	480	1,620	22	405	240	500
Pour, °F.	−10	−10	0	−5	−5	0	0	−5	−5
Alkali absorption, mg. KOH per gram	0.299	0.02	0.509	1.00	0.025	0.60	0.04	0.36	0.05
Corrosion	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.
Flash, °F.	370	365	355	370	365	340	340+	345	350
Fire, °F.	410	410	405	415	420	400	395	410	410
Carbon residue, per cent	0.10	0.095	0.110	0.095	0.09	0.145	0.096	0.07	0.09
Ash, per cent	None.	None.	0.010	None.	None.	0.015	None.	None.	None.
Sulphur, per cent	0.65	0.74	0.77	0.58	0.61	0.78	0.75	0.58	0.57
I. b. p. (40 mm.), °F.	392	378	369	405	410	336	345	361	372
Oxidation, mg. per 15 gram	90	11	136	56	16	216	22	35	38

[1] Did not pass. [2] Difficult to determine exactly.

TABLE 2.—*Data on new oils used in comparisons*

Oil	Demulsibility [1]	Emulsion, NaOH	R. E. number	Alkali absorption	I. b. p., 40 mm. absolute	Flash	Oxidation	Carbon residue
	150 °F.	*Per cent*		*Mg. KOH per gram*	*°F.*	*°F.*	*Mg. per 15 gram*	*Per cent*
A-1	460	0.0	1.5	0.02	378	365	11	0.10
A-2	120	87.5	7.0	.51	369	355	136	.11
B-1	480	51.5	1.5+	1.00	405	370	56	.10
B-2	1,620	0	1.0	.03	410	365	16	.09
C-1	22	56.2	17.5	.60	336	340	216	.15
C-2	405	0	7–11	.04	345	340+	22	.10
D-1	240	52.5	2¼	.36	361	345	35	.07
D-2	500	27.5	1.75	.05	372	350	38	.09
S-2	223	91.3	2.0	.30	392	370	90	.10

[1] See p. 27 for discussion of results of demulsibility and emulsion tests.

TABLE 3.—*Flash points, viscosity increase, and fractional distillation of test oils*

Oil	Average viscosity increase	Flash point	I. b. p., 40 mm. absolute	Percentage distilled					
				40 mm.					15 mm.
				392° F.	437° F.	482° F.	527° F.	572° F.	572° F.
		°F.	*°F.*						
A-1	50	365	378	1.1	8.6	24.6	45.6	74.8	90.8
A-2	75	355	369	1.9	10.4	26.1	50.4	68.3	88.1
B-1	53	370	405	----------	6.7	28.1	51.7	76.6	92.3
B-2	28	365	410	----------	2.8	19.4	51.3	78.4	94.2
C-1	128	340	336	3.7	13.3	31.4	54.1	75.6	91.1
C-2	130	340+	345	3.0	11.3	27.8	50.8	70.6	87.9
D-1	55	345	361	1.3	6.7	24.0	51.8	78.2	92.0
D-2	46	350	372	1.2	7.3	24.1	53.0	77.4	93.0

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TABLE 4.—*Gravity and viscosity of first and last 10 per cent fractions of test oils (Distillation at 10 mm. pressure absolute)*

Oil	First 10 per cent		Ten per cent residuum	
	Gravity ° A. P. I.	Viscosity at 100° F.	Gravity ° A. P. I.	Viscosity at 210° F.
A-1	24.2	52.2	19.1	129.4
A-2	24.2	49.0	17.8	151.7
B-1	22.4	63.1	16.5	142.0
B-2	22.3	66.0	17.1	119.0
C-1	24.6	49.4	15.8	195.5
C-2	25.1	48.2	16.4	191.7
D-1	23.9	55.5	17.3	139.7
D-2	24.0	55.3	17.2	145.8

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TABLE 5A.—*Engine-test data*

[In order of run]

Log	Oil	Oil consumption, pounds	Torque, pounds			Speed, r. p. m			Average b. h. p.	Total fuel consumption for 7 hours, pounds	Specific fuel consumption, pounds per horsepower hour	Manifold pressure, mm.	Barometer average, mm.	Absolute manifold pressure, mm.	Room temperature range, ° F.	Average oil temperature, ° F.	Average outlet water temperature, ° F.	Average difference of water temperature, ° F.	Oil pressure, pounds		Pressure difference, pounds	Temperature factor [1]
			Maximum	Minimum	Average	Maximum	Minimum	Average											Maximum	Minimum		
7	S-2	6.13	97.4	96.1	96.7	1,659	1,617	1,644	39.75	146.25	0.527	651	764.1	113.1	70–85	185.5	178	28.7	21	17	4	65.20
8	A-1	4.64	95.6	93.6	95.07	1,623	1,600	1,609	38.25	141.75	.53	651	759.8	108.8	80–88	187.2	184.8	32.6	26	16	10	64.50
9	A-2	6.88	98.0	96.2	97.3	1,647	1,614	1,623	39.5	141.37	.512	651	758.4	107.4	78–87	186.2	178.7	30.7	26	18	8	64.40
10	S-2	6.44	96.2	93.5	94.88	1,627	1,601	1,613	38.3	139.5	.521	651	765	114	76–85	184.7	179.6	30	28	16	12	63.06
11	A-2	5.89	100.3	99.5	99.9	1,612	1,592	1,601	40.0	147.0	.525	651	760.3	109.7	74–79	184.3	179.7	31.2	24	20	14	65.64
12	A-1	6.26	100.0	94.6	97.8	1,637	1,609	1,621	39.65	144.25	.533	651	763.8	112.8	74–94	185.1	178.8	31.1	30	20	10	64.75
13	S-2	7.25	94.6	92.4	93.86	1,650	1,614	1,636	38.4	141.17	.525	654	765.7	111.7	73–85	185.3	181.7	33.1	32	14	18	63.42
14	B-1	8.29	100.0	97.3	99.0	1,613	1,597	1,604	39.7	145.0	.522	652	768.5	116.5	70–85	184.2	183.9	35.2	28	14	18	66.00
15	B-2	6.19	95.0	92.8	94.0	1,618	1,594	1,606	37.72	140.0	.530	652	762.5	110.5	72–89	185.5	180.4	32.4	30	20	10	61.94
16	S-2	6.26	95.2	93.5	94.6	1,623	1,595	1,606	38.0	141.62	.532	655	760.9	105.9	78–86	184.6	183.1	35.2	30	20	10	62.90
17	B-2	5.82	94.7	93.0	94.07	1,622	1,595	1,610	37.85	141.5	.535	653	765.6	112.6	71–86	184.5	177.3	32	30	20	10	61.10
18	B-1	7.29	95.6	92.7	94.5	1,627	1,597	1,608	38.0	144.5	.542	656	765.3	109.3	75–89	184.7	181.5	34.2	28	18	10	62.50
[2]19	S-2	7.26	93.8	92.8	93.2	1,638	1,602	1,616	37.65	141	.535	655	763.6	108.6	74–82	184.3	183.6	35.3	28	18	10	62.50
20	S-2	6.17	94.8	93.0	94.3	1,613	1,591	1,603	37.75	141.5	.536	652	765	113	66–82	184.9	181.7	28.3	28	18	10	63.25
21	C-1	8.95	96.4	93.2	95.03	1,613	1,590	1,602	38.10	141.25	.530	650	767.8	117.8	70–83	184.2	183.7	31.9	28	10	18	63.88
22	C-2	8.60	96.0	93.5	94.77	1,619	1,600	1,609	37.12	141.75	.531	648	772.1	124.1	67–82	186.2	181.8	32.8	26	10	16	61.40
23	S-2	8.08	94.0	91.8	92.95	1,612	1,583	1,602	37.2	141.5	.543	653	764.8	111.8	68–81	184.2	183.2	34.2	26	10	16	61.80
24	C-2	8.83	95.0	92.0	93.77	1,620	1,600	1,608	37.7	141.5	.536	651	774	123	60–77	184.1	182.4	32.1	26	10	16	62.70
25	C-1	9.89	96.0	91.6	94.3	1,623	1,598	1,609	37.9	142.25	.536	646	766.3	120.3	61–79	183.9	183.3	32.4	28	8	20	63.40
26	S-2	9.57	95.0	90.5	93.75	1,609	1,590	1,599	37.48	139	.530	651	772.7	121.7	60–80	184.9	185.5	34.2	26	10	16	63.10
27	D-1	9.62	96.0	92.8	94.55	1,617	1,596	1,607	38.0	142	.534	638	764.9	126.9	65–83	185	180.4	34.3	28	10	18	62.08
28	D-2	8.39	87.5	83.7	85.5	1,610	1,592	1,602	31.4	140	.584	[3]668	764	96	66–83	185.3	182.6	32.4	28	12	16	57.30
30	S-2	8.27	91.8	89.0	90.49	1,620	1,596	1,606	36.35	140.6	.553	651	772	121	66–83	185.4	184.1	34	28	14	14	60.75
[4]31	D-2	10.75	94.0	90.0	92.85	1,613	1,588	1,605	37.28	143	.548	643	769.5	126.5	64–82	185.2	185.3	33.9	30	8	22	62.80
32	D-1	9.07	92.2	89.0	91.0	1,627	1,590	1,607	36.55	141.5	.553	648.8	764.8	116	71–83	185	184.4	34.4	28	12	16	61.10
[5]33	S-2	9.45	91.6	88.4	90.2	1,620	1,587	1,603	36.2	138.25	.546	646.4	771.7	125.3	70–84	185.1	185	31.5	28	12	16	61.30
35	S-2	9.13	94.0	90.6	92.83	1,620	1,591	1,606	37.27	143.5	.556	648	762.4	114.4	72–84	183.1	177	23	30	10	20	61.68
36	S-2	7.75	95.0	93.2	94.2	1,626	1,604	1,616	38.1	146.25	.55	657	758.	101.	69–80	184	181	22	30	14	16	64.80
37	S-2	8.79	91.2	89.0	90.2	1,622	1,591	1,607	36.3	141.0	.555	667	765.7	98.7	66–81	185	183	22	30	14	16	62.45
38	S-2	9.05	95.0	93.4	94.4	1,626	1,600	1,617	38.18	142.75	.534	657	764.7	107.7	70–81	185	185	22	30	14	16	64.40

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39	S-2	8.67	94.4	92.0	93.4	1,620	1,600	1,610	37.6	142.75	.542	658.5	762.2	103.7	70–88	185	184.5	21	30	12	18	65.60
40	D-1	8.85	89.0	86.4	87.9	1,616	1,594	1,606	35.28	139.5	.565	693.5	764.6	101.1	72–85	185	184.0	20	30	14	16	61.40
41	D-2	9.14	94.6	92.0	93.76	1,612	1,587	1,604	37.6	141.75	.538	651	767.0	116	68–82	185	185	20	30	12	18	65.80
42	S-2	8.01	93.6	91.0	92.2	1,613	1,593	1,607	37.1	143.75	.554	654.6	769.3	114.7	72–86	185	185	21	30	14	16	64.75
43	D-2	8.58	93.6	92.4	93.0	1,624	1,602	1,614	37.5	145.25	.553	658	761	103	70–83	185−	184−	24	30	14	16	64.50
44	D-1	8.76	94.4	92.2	93.5	1,620	1,604	1,612	37.7	145.5	.552	651	762.3	111.3	68–82	185	185	20	30	12	18	66.00
45	S-2	7.02	93.4	92.0	92.9	1,624	1,600	1,612	37.4	146.87	.56	658.5	765.6	107.1	70–85	185	184	20	30	16	14	65.10
46	A-1	9.53	95.6	93.8	95.0	1,626	1,606	1,617	38.4	147.5	.548	651	764.6	113.6	68–83	185	185	20	30	12	18	67.20
47	A-2	9.04	95.6	93.6	94.9	1,618	1,596	1,608	38.2	147.5	.552	642.5	757.1	114.6	70–81	185	185	22	32	12	20	66.30
48	S-2	7.55	96.0	95.0	95.6	1,621	1,604	1,614	38.6	148.5	.55	650.3	764.8	114.5	71–84	185+	184	19.5	28	16	12	67.25
49	A-2	7.83	96.4	94.2	94.22	1,621	1,596	1,607	37.87	146.25	.548	647.4	765.3	117.9	75–94	185	185	20	28	14	14	66.30
50	A-1	8.42	96.8	96.2	96.43	1,630	1,600	1,616	38.98	150.5	.552	646.5	761.3	114.8	70–82	185.6	184.8	21.7	28	14	14	67.80
51	S-2	8.06	95.6	94.6	95.15	1,620	1,603	1,610	38.6	148.75	.552	645.3	760.5	115.2	72–81	185.1	184.5	20.5	28	14	14	67.25
52	S-2	8.72	93.6	91.2	93.0	1,610	1,593	1,602	37.5	144.75	.554	654.1	759.0	104.9	72–84	185	185	20	32	14	18	65.60
[4] 53	B-2	8.35	96.4	94.2	95.65	1,620	1,593	1,607	38.35	147.0	.548	645.5	760	114.5	70–86	185.5	185	21	38	14	24	66.90
54	S-2																					
55	S-2																					
56	S-2	9.63	88.4	86.4	87.25	1,604	1,574	1,591	34.74	145	.597	643	763.5	120.5	70–86	184.6	184.5	20.5	27	10	17	60.57
57	S-2																					
58	S-2	8.09	90.0	89.2	89.6	1,637	1,605	1,617	36.20	138.37	.546	652.7	764.3	111.6	71–87	185	182	19.8	28	16	12	62.30
59	S-2	8.37	91.2	89.2	90.57	1,620	1,595	1,608	36.40	139.37	.547	656	760.5	104.5	72–83	185	185	21	27	14	13	63.50
60	B-2	8.77	92.2	91.4	91.86	1,622	1,600	1,614	37.1	140.25	.541	656	763.8	107.8	72–84	184.5	184.7	19	28	12	16	65.00
61	S-2	10.29	92.2	91.0	92.0	1,617	1,601	1,610	37.05		.542	655	760.3	105.3	72–85	184.6	184.5	20.5	27	8	19	64.60
62	C-1	9.89	92.0	91.0	91.7	1,621	1,603	1,614	37	141.0	.544	655	761.6	106.6	73–83	184.9	184.0	18.8	28	16	12	63.60
63	S-2	10.32	92.8	92.2	92.5	1,624	1,606	1,616	37.38	141.12	.540	655	760.4	105.4	70–86	185.0	183.9	16.9	27	13	14	65.55
64	S-2	11.22	94.6	93.4	94.1	1,632	1,597	1,617	38.05	144.12	.541	652	763.3	111.3	72–84	185.4	184.4	18.4	27	11	16	66.65

[1] See p. 28.
[2] Valves ground and bearings taken up after run 19.
[3] Leak in line to pressure gauge.
[4] Burned wrist pin, run 31.
[5] Engine overhauled before run 35.
[6] New bearing after run 53.

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TABLE 5B.—*Engine-test data*

[Arranged by oils]

Log	Oil	Oil consumption, pounds	Torque, pounds			Speed, r. p. m.			Average b. p. h.	Total fuel consumption for 7 hours, pounds	Specific fuel consumption, pounds per horsepower hour	Manifold pressure, mm.	Barometer average, mm.	Absolute manifold pressure, mm.	Room-temperature range, °F.	Average oil temperature, °F.	Average outlet water temperature, °F.	Average difference of water temperature, °F.	Oil pressure, pounds		Pressure difference, pounds	Temperature factor [1]
			Maximum	Minimum	Average	Maximum	Minimum	Average											Maximum	Minimum		
7	S-2	6.13	97.4	96.1	96.7	1,659	1,617	1,644	39.8	146.3	0.527	651	764.1	113.1	70–85	185.5	178	28.7	21	17	4	65.20
10	S-2	6.44	96.2	95.3	94.9	1,627	1,601	1,613	38.3	139.5	.521	651	765.	114	76–85	184.7	179.6	30	28	16	12	63.06
13	S-2	7.25	94.6	92.4	93.9	1,650	1,614	1,636	38.4	141.2	.525	654	765.7	111.7	73–85	185.3	181.7	33.1	32	14	18	63.42
16	S-2	6.26	95.2	93.5	94.6	1,623	1,595	1,606	38.0	141.6	.532	655	760.9	105.9	78–86	184.6	183.1	35.2	30	20	10	62.90
19	S-2	7.26	93.8	92.8	93.2	1,638	1,602	1,616	37.7	141.0	.535	655	763.6	108.6	74–82	184.3	183.6	35.3	28	18	10	62.50
20	S-2	6.17	94.8	93.0	94.3	1,613	1,591	1 603	37.8	141.5	.536	652	765	113	66–82	184.9	181.7	28.3	28	18	10	63.25
23	S-2	8.08	94.0	91.8	93.0	1,612	1,583	1,602	37.2	141.5	.543	653	764.8	111.8	68–81	184.2	183.2	34.2	26	10	16	61.80
26	S-2	9.57	95.0	90.5	93.8	1,609	1,590	1,599	37.5	139	.530	651	772.7	121.7	66–80	184.9	185.5	34.2	26	10	16	63.10
307	S-2	8.27	91.8	89.0	90.5	1,620	1,596	1,606	36.4	140.6	.553	651	772	121	66–83	185.4	184.1	34	28	14	14	60.75
33	S-2	9.45	91.6	88.4	90.2	1,620	1,587	1,603	36.2	138.3	.546	646.4	771.7	125.3	70–84	185.1	185	31.5	28	12	16	61.30
335	S-2	9.13	94.0	90.6	92.8	1,620	1,591	1,606	37.3	143.5	.556	648	762.4	114.4	72–84	183.1	177	23	30	10	20	61.68
36	S-2	7.75	95.0	93.2	94.2	1,626	1,604	1,616	38.1	146.3	.55	657	758	101	69–80	184	181	22	30	14	16	64.80
37	S-2	8.79	91.2	89.0	90.2	1,622	1,591	1,607	36.3	141	.555	657	765.7	98.7	66–81	185	183	22	30	14	16	62.45
38	S-2	9.05	95.0	93.4	94.4	1,626	1,600	1,617	38.2	142.8	.534	657	764.7	107.7	70–81	185	185	22	30	14	16	66.40
39	S-2	8.67	94.4	92.0	93.4	1,620	1,600	1,610	37.6	142.8	.542	658.5	762.2	103.7	70–88	185	184.5	21	30	12	18	65.60
42	S-2	8.01	93.6	91.0	92.2	1,613	1,593	1,607	37.1	143.8	.554	654.6	769.3	114.7	72–86	185	185	21	30	14	16	64.75
45	S-2	7.02	93.4	92.0	92.9	1,624	1,600	1,612	37.4	146.9	.560	658.5	765.6	107.1	70–85	185	184	20	30	16	14	65.10
48	S-2	7.55	96.0	95.0	95.6	1,621	1,604	1,614	38.6	148.5	.55	650.3	764.8	114.5	71–84	185+	184	19.5	28	16	12	67.25
51	S-2	8.06	95.6	94.6	95.2	1,620	1,603	1,610	38.6	148.8	.552	645.3	760.5	115.2	72–81	185.1	184.5	20.5	28	14	14	67.25
52	S-2	8.72	93.6	91.2	93.0	1,610	1,593	1,602	37.5	144.8	.554	654.1	759.0	104.9	72–84	185	185	20	32	14	18	65.60
56	S-2	9.63	88.4	86.4	87.3	1,604	1,574	1,591	34.7	145.0	.597	643	763.5	120.5	70–86	184.6	184.5	20.5	27	10	17	60.57
58	S-2	8.09	90.0	89.2	89.6	1,637	1,605	1,617	36.2	138.4	.546	652.7	764.3	111.6	71–87	185	182	19.8	28	16	12	62.30
59	S-2	8.37	91.2	89.2	90.6	1,620	1,595	1,608	36.4	139.4	.547	656	760.5	104.5	72–83	185	185	21	27	14	13	63.50
61	S-2	10.29	92.2	91.0	92.0	1,617	1,601	1,610	37.1	-------	.542	655	760.3	105.3	72–85	184.6	184.5	20.5	27	8	19	64.60
63	S-2	10.32	92.8	92.2	92.5	1,624	1,606	1,616	37.4	141.1	.540	655	760.4	105.4	70–86	185.0	183.9	16.9	27	13	14	65.55
64	S-2	11.22	94.6	93.4	94.1	1,632	1,597	1,617	38.1	144.1	.541	652	763.3	111.3	72–84	185.4	184.4	18.4	27	11	16	66.65
8	A-1	4.64	95.6	93.6	95.1	1,623	1,600	1,609	38.3	141.8	.53	651	759.8	108.8	80–88	187.2	184.8	32.6	26	16	10	64.50
12	A-1	6.26	100.0	94.6	97.8	1,637	1,609	1,621	39.7	144.3	.533	651	763.8	112.8	74–94	185.1	178.8	31.1	30	20	10	64.75
46	A-1	9.53	95.6	93.8	95.0	1,626	1,606	1,617	38.4	147.5	.548	651	764.6	113.6	68–83	185	185	20	30	12	18	67.20
50	A-1	8.42	98.8	96.2	96.4	1,630	1,600	1,616	39.0	150.5	.552	646.5	761.3	114.8	70–82	185.6	184.8	21.7	28	14	14	67.80

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9	A-2	6.88	98.0	96.2	97.3	1,647	1,614	1,623	39.5	141.4	.512	651	758.4	107.4	78–87	186.2	178.7	30.7	26	18	8	64.40
11	A-2	5.89	100.3	99.5	99.9	1,612	1,592	1,601	40.0	147	.525	651	760.3	109.7	74–79	184.3	179.7	31.2	24	20	4	65.64
47	A-2	9.04	95.6	93.6	94.9	1,618	1,596	1,608	38.2	147.5	.522	642.5	757.1	114.6	70–81	185	185	22	32	12	20	66.30
49	A-2	7.83	96.4	94.2	94.2	1,621	1,596	1,607	37.9	146.3	.548	647.4	765.3	117.9	75–94	185	185	20	28	14	14	66.30
14	B-1	8.29	100.0	97.3	99.0	1,613	1,597	1,604	39.7	145	.522	652	768.5	116.5	70–85	184.2	183.9	35.2	28	14	14	66.00
18	B-1	7.29	95.6	92.7	94.5	1,627	1,597	1,608	38.0	144.5	.542	656	765.3	109.3	75–89	184.7	181.5	34.2	28	18	10	62.50
15	B-2	6.19	95.0	92.8	94.0	1,618	1,594	1,606	37.7	140	.530	652	762.5	110.5	72–89	185.5	180.4	32.4	30	20	10	61.94
17	B-2	5.82	94.7	93.0	94.1	1,622	1,595	1,610	37.9	141.5	.535	653	765.6	112.6	71–86	184.5	177.3	32	30	20	10	61.10
53	B-2	8.35	96.4	94.2	95.7	1,620	1,593	1,607	38.4	147.0	.548	645.5	760	114.5	70–86	185.5	185	21	38	14	24	66.90
60	B-2	8.77	92.2	91.4	91.9	1,622	1,600	1,614	37.1	140.3	.541	656	763.8	107.8	72–84	184.5	184.7	19	28	12	16	65.00
21	C-1	8.95	96.4	93.2	95.0	1,613	1,590	1,602	38.1	141.3	.530	650	767.8	117.8	70–83	184.2	183.7	31.9	28	10	18	63.88
25	C-1	9.89	96.0	91.6	94.3	1,623	1,598	1,609	37.9	142.3	.536	646	766.3	120.3	61–79	183.9	183.3	32.4	28	8	20	63.40
62	C-1	9.89	92.0	91.0	91.7	1,621	1,603	1,614	37.0	141.0	.544	655	761.6	106.6	73–83	184.9	184.0	18.8	28	16	12	63.60
22	C-2	8.60	96.0	93.5	94.8	1,619	1,600	1,609	37.1	141.8	.531	648	772.1	124.1	67–82	186.2	181.8	32.8	26	10	16	61.40
24	C-2	8.83	95.0	92.0	93.8	1,620	1,600	1,608	37.7	141.5	.536	651	774	123	60–77	184.1	182.4	32.1	26	10	16	62.70
27	D-1	9.62	96.0	92.8	94.5	1,617	1,596	1,607	38.0	142	.534	638	764.9	126.9	65–83	185	180.4	34.3	28	10	18	62.08
32	D-1	9.07	92.2	89.0	91.0	1,627	1,590	1,607	36.6	141.5	.553	648.8	764.8	116	71–83	185	184.4	34.4	28	12	16	61.10
40	D-1	8.85	89.0	86.4	87.9	1,616	1,594	1,606	35.3	139.5	.565	663.5	764.6	101.1	72–85	185	184.0	20	30	14	16	61.40
44	D-1	8.76	94.4	92.2	93.5	1,620	1,604	1,612	37.7	145.5	.552	651	762.3	111.3	68–82	185	185	20	30	12	18	66.00
29	D-2	8.39	87.5	83.7	85.5	1,610	1,592	1,602	34.4	140	.584	[3] 668	764	96	66–83	185.3	182.6	32.4	28	12	16	57.30
31	D-2	10.75	94.0	90.0	92.9	1,613	1,588	1,605	37.3	143	.548	643	769.5	126.5	64–82	185.2	185.3	33.9	30	8	22	62.80
41	D-2	9.14	94.6	92.0	93.8	1,612	1,587	1,604	37.6	141.8	.538	651	767	116	68–82	185	185	20	30	12	18	65.80
43	D-2	8.58	93.6	92.4	93.0	1,624	1,602	1,614	37.5	145.3	.553	658	761	103	70–83	185–	184–	24	30	14	16	64.50

[1] See p. 28.

[3] Overhaul between runs 33 and 34.

[3] Leak in line to pressure gauge.

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TABLE 6.—*Oil consumption (showing method of averaging)*

Oil	Total consumption of oil, pounds					
	First run	Second run	Third run	Average	Correction	Corrected average consumption
A-1	4.64	6.26		5.45		5.45
A-2	6.88	5.89		6.39		6.39
S-2	6.13	6.44	7.25	6.61		6.61
B-1	8.29	7.29		7.79	−0.31	7.48
B-2	6.19	5.82		6.01	−0.31	5.70
S-2	7.25	6.26	7.26	6.92	−0.31	6.61
C-1	8.95	9.89		9.42	−1.34	8.08
C-2	8.60	8.33		8.47	−1.34	7.13
S-2	6.17	8.08	9.57	7.95	−1.34	6.61
D-1	9.62	9.07		9.35	−2.49	6.86
D-2	8.39	[1] 10.75		9.57	−2.49	7.08
S-2	9.57	8.27	9.45	9.10	−2.49	6.61
D-1	8.85	8.76		8.81	−1.29	7.52
D-2	9.14	8.58		8.86	−1.29	7.57
S-2	8.67	8.01	7.02	7.90	−1.29	6.61
A-1	9.53	8.42		8.98	−0.93	8.05
A-2	9.04	7.83		8.44	−0.93	7.51
S-2	7.02	7.55	8.06	7.54	−0.93	6.61

[1] Burned wrist pin this run.

TABLE 7.—*Torque on test runs, corrected and averaged*

Oil	Average torque, in pounds, 15¾-inch arm [1]					
	First run	Second run	Third run	Average	Correction multiplier	Corrected average
A-1	95.1	97.8		96.5	1.000	96.5
A-2	97.3	99.9		98.6	1.000	96.6
S-2	96.7	94.9	93.9	95.2	1.000	95.2
B-1	99.0	94.5		96.8	1.014	98.2
B-2	94.0	94.1		94.1	1.014	95.4
S-2	93.9	94.6	93.2	93.9	1.014	95.2
C-1	95.0	94.3		94.7	1.016	96.2
C-2	94.8	93.8		94.3	1.016	95.8
S-2	94.3	93.0	93.8	93.7	1.016	95.2
D-1	94.6	91.0		92.8	1.067	99.0
D-2	85.5	92.9		89.2	1.067	95.2
S-2	93.8	90.5	90.2	91.5	1.067	95.2
S-2	92.8	94.2	90.2 94.4 93.4	93.0		
D-1	87.9	93.5		90.7	1.025	93.0
D-2	93.8	93.0		93.4	1.025	95.8
S-2	93.4	92.2	92.9	92.8	1.025	95.2
A-1	95.0	96.4		95.7	1.006	96.3
A-2	94.9	94.2		94.6	1.006	95.2
S-2	92.9	95.6	95.2	94.6	1.006	95.2

[1] Average torque for last 7 hours of run. Torque for first hour frequently erratic and consequently omitted.

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TABLE 8.—*Average horsepower output*

Oil	First run	Second run	Third run	Average
A-1	38.3	39.7	----------	39.0
A-2	39.5	40.0	----------	39.8
S-2	39.8	38.3	38.4	38.8
B-1	39.7	38.0	----------	38.9
B-2	37.7	37.9	----------	37.8
S-2	38.4	38.0	37.7	38.0
C-1	38.1	37.9	----------	38.0
C-2	37.1	37.7	----------	37.4
S-2	37.8	37.2	37.5	37.5
D-1	38.0	36.6	----------	37.3
D-2	[1] 34.4	37.3	----------	35.9
S-2	37.5	36.4	36.2	36.7
S-2 [2]	{ 37.3 38.1	36.3 38.2	} 37.6	----------
D-1 [3]	35.3	37.7	----------	36.5
D-2	37.6	37.5	----------	37.6
S-2	37.6	37.1	37.4	37.4
A-1	38.4	39.0	----------	38.7
A-2	38.2	37.9	----------	38.1
S-2	37.4	38.6	38.6	38.2

[1] High manifold pressure due to leak in pressure-gauge line.
[2] Five successive runs on oil S-2 after overhaul.
[3] This and five that follow are reruns after overhaul.

TABLE 9.—*Temperature factors* [1] *(arranged and averaged)*

Oil	First run	Second run	Third run	Average
A-1	64.50	64.75	----------	64.63
A-2	64.40	65.64	----------	65.02
S-2	65.20	63.06	63.42	63.89
B-1	66.00	62.50	----------	64.25
B-2	61.94	61.10	----------	61.52
S-2	63.42	62.90	62.50	62.94
C-1	63.88	63.40	----------	63.64
C-2	61.40	62.70	----------	62.05
S-2	63.25	61.80	63.10	62.72
D-1	62.08	61.10	----------	61.59
D-2	[2] 57.30	62.80	----------	60.05
S-2	63.10	60.75	61.30	61.72
S-2 [3]	{ 61.68 64.80	62.45 66.40	} 65.60	----------
D-1	61.40	66.00	----------	63.70
D-2	65.80	64.50	----------	65.15
S-2	65.60	64.75	65.10	65.15
A-1	67.20	67.80	----------	67.50
A-2	66.30	66.30	----------	66.30
S-2	65.10	67.25	67.25	66.53

[1] See p. 28.
[2] High manifold pressure due to leak in pressure-gauge line.
[3] Five successive runs after overhaul.

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TABLE 10A.—*Changes in properties of test oils*

[In the order run]

Log	Oil	Viscosity, seconds				Alkali-absorption number				Carbon residue, per cent				Piston carbon, grams	Combustion-chamber carbon, grams	Insolubles, per cent by weight		
		Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours	Initial	Increase after 1 hour	Increase after 4 hours	Increase after 8 hours	Initial	Increase after 1 hour	Increase after 4 hours	Increase after 8 hours			After 1 hour	After 4 hours	After 8 hours
7	S-2	302	−1	+11	+51	0.30	0.0	0.20	0.59	0.10	0.03	0.14	0.34	2.28	5.21	0.044	0.110	0.316
8	A-1	293	0	15	46	.02	.05	.26	.37	.10	.0	.04	.21	1.36	5.14	.023	.086	.216
9	A-2	297	1	20	74	.51	.0	.26	1.00	.11	.02	.07	.41	1.31	6.13	.024	.096	.310
10	S-2	302	0	12	41	.30	.08		.64	.10	.04	.12	.33	1.92	6.38	.021	.088	.273
11	A-2	297	−3	20	70	.51	.10	.14	.87	.11	.05	.15	.36	1.67	5.43	.044	.085	.288
12	A-1	293	−1	16	56	.02	.07	.28	.32	.10	.0	.04	.31	1.50	2.96	.025	.082	.240
13	S-2	302	−4	13	55	.30	.13	.29	.74	.10	.04	.08	.37	2.27	6.31	.045	.129	.282
14	B-1	302	−7	9	53	1.00	.12	.14	.50	.10	.04	.19	.50	2.00	8.43	.022	.089	.328
15	B-2	307	−11	−5	25	.03	.06	.18	.64	.09	.04	.09	.32	1.41	5.57	.036	.119	.227
16	S-2	302	−8	7	51	.30	.10	.27	.33	.10	.04	.15	.29	1.52	5.45	.030	.104	.294
17	B-2	307	−10	−5	30	.03	.03	.12	.69	.09	.03	.13	.26	1.29	5.04	.010	.067	.230
18	B-1	302	−5	7	52	1.00	.07	.19	.73	.10	.03	.18	.36	1.37	6.87	.005	.083	.286
19	S-2	302	−8	8	52	.30	.17	.30	.45	.10	.0	.11	.46	1.60	7.07	.019	.090	.275
20	S-2	302	−8	8	54	.30	.19	.57	.89	.10	.02	.15	.38	1.35	5.76	.010	.071	.263
21	C-1	338	−5	34	128	.60	.15	.66	.67	.15	.0	.20	.41	2.41	7.99	.041	.196	.530
22	C-2	334	0	39	133	.04	.15	.40	.91	.10	.04	.15	.36	1.85	8.19	.027	.165	.513
23	S-2	302	−6	12	64	.30	.19	.34	.96	.10	.03	.09	.28	1.66	7.38	.017	.081	.323
24	C-2	334	0	38	127	.04	.15	.48	.89	.10	.0	.14	.43	2.02	8.52	tr.	.117	.433
25	C-1	338	0	36	128	.60	.55	.06	.91	.15	.04	.16	.46	2.62	8.18	.027	.209	.566
26	S-2	302	−8	12	70	.30	.14	.47	.80	.10	.04	.16	.38	2.82	6.40	.009	.162	.523
27	D-1	302	−3	16	70	.36	.09	.14	.75	.07	.06	.15	.35	3.38	6.59	.029	.178	.448
29	D-2	297	−3	3	43	.05	.06	.15	.50	.09	.02	.10	.20	1.65	6.98	.030	.105	.276
30	S-2	302	−6	12	59	.30	.26	.31	1.04	.10	.03	.13	.33	1.70	7.90	.007	.102	.358
31	D-2	297	−5	18	61	.05	.06	.11	.85	.09	.04	.12	.27	3.41	6.59	Tr.	.132	.379
32	D-1	302	−4	15	62	.36	.0	.29	.47	.07	.03	.14	.26	1.94	7.47	.024	.107	.353
33	S-2	302	−6	12	66	.30	.20	.53	.53	.10	.0	.09	.36	1.46	8.02	.034	.142	.400
35	S-2	302			61	.30				.10			.36	3.65	9.49			.394
36	S-2	302			44	.30				.10			.36	2.29	9.53			.318
37	S-2	302			45	.30				.10				2.38	8.86			.341
38	S-2	302			50	.30				.10				2.42	10.38			.366

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30	S-2	302	−6		3	44	.30					.10																		.278
40	D-1	302	−6		2	42	.35	.22		.39		.07	.04		.25	2.59														.293
41	D-2	297	−8		−1	41	.05	.10	.14	.70		.08	.05	.11	.29	1.80														.310
42	S-2	302	−8		3	41.5	.30	.04	.23	.97		.10	.0	.14	.24	3.25														.288
43	D-2	297	−8			40	.05	.17	.17	.55		.08	.0	.06	.30	2.52														.246
44	D-1	302	−8		4	46	.35	.19	.18	.35		.07	.05		.24	2.74	8.84	.009												.319
45	S-2	302	−8		−1	36	.30	.22	.35	1.09		.10	.0	.07	.26	2.69	10.64	Tr.												.222
46	A-1	298	−13		5	34	.03	.11	.20			.10	.0	.06	.22	2.77	8.19	.043												.305
47	A-2	297	−2		17	81.5	.01					.11		.06	.27	2.46	9.97	Tr.												.296
48	S-2	302	−7		5	50	.30					.10			.35	2.51														.327
49	A-2	297	−1		17	72	.51					.11			.37	2.07	8.64													.310
50	A-1	298	−8		4	43	.02					.10			.23	2.88	8.54													.306
51	S-2	302	−6		2	48	.30					.10			.23	3.39	8.75													.329
52	S-2	302				43	.30					.10																		.334
53	B-2	307				34	.05					.08																		.322
56	S-2	302				60	.30					.10																		.751
58	S-2	302				58	.30					.10																		.370
59	S-2	302				61	.30					.10																		.358
60	B-2	307				44	.05					.08																		.339
61	S-2	302				67	.30					.10																		.456
62	C-1	338				114	.60					.15																		.437
63	S-2	302				72	.30					.10																		.496
64	S-2	302				80	.30					.10																		.500

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TABLE 10A.—*Changes in properties of test oils*—Continued

Log	Oil	Flash, °F.				Fires, °F.				Demulsibility	Emulsion, per cent	Oxidation number	R. E. number	I. b. p. at 40 mm., °F.	Residue 300 °C. 15 mm.	Total insolubles, pounds / 1,000	Oil consumption, pounds
		Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours	Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours								
7	S-2	370	0	−10	−30	410	5	0	5	223	91.3	90	2.0	392	7.9	28.8	6.13
8	A-1	365	10	−25	−20	410	−10	−10	0	460	0	11	1.5	378	9.2	24.4	4.64
9	A-2	355	10	−10	0	405	−10	−5	0	120	87.5	136	7.0	369	11.9	27.1	6.88
10	S-2	370	−10	−25	−25	410	−5	0	0	223	91.3	90	2.0	392	7.9	25.9	6.44
11	A-2	355	0	−5	−20	405	−10	0	5	120	87.5	136	7.0	369	11.9	27.7	5.89
12	A-1	365	−15	−25	−25	410	−5	−5	0	460	0	11	1.5	378	9.2	22.7	6.26
13	S-2	370	−20	−20	−25	410	0	0	0	223	91.3	90	2.0	392	7.9	23.3	7.25
14	B-1	370	5	−10	−25	415	5	0	0	480	51.5	56	1.5	405	7.7	23.4	8.29
15	B-2	365	−15	0	−15	420	0	0	0	1,620	0	16	1.0	410	5.8	21.5	6.19
16	S-2	370	−15	−25	−20	410	5	0	0	223	91.3	90	2.0	392	7.9	28.0	6.26
17	B-2	365	−10	0	−10	420	0	0	0	1,620	0	16	1.0	410	5.8	23.1	5.82
18	B-1	370	−15	−30	−30	415	0	−5	−5	480	51.5	56	1.5	405	7.7	24.4	7.29
19	S-2	370	−15	−30	−20	410	5	0	10	223	91.3	90	2.0	392	7.9	23.6	7.26
20	S-2	370	−15	−25	−25	410	0	5	5	223	91.3	90	2.0	392	7.9	25.8	6.17
21	C-1	340	−10	5	5	400	−5	0	5	22	56.2	216	18.0	336	8.9	37.3	8.95
22	C-2	340+	−10	−10	−10	395	0	0	0	405	0	22	9.0	345	12.1	36.4	8.60
23	S-2	370	−20	−30	−20	410	0	0	5	223	91.3	90	2.0	392	7.9	25.1	8.08
24	C-2	340+	−10	−20	−5	395	−5	5	5	405	0	22	9.0	345	12.1	30.5	8.83
25	C-1	340	−15	−10	−5	400	0	0	5	22	56.2	216	18.0	336	8.9	34.6	9.89
26	S-2	370	−20	−25	−20	410	5	5	5	223	91.3	90	2.0	392	7.9	33.5	9.57
27	D-1	345	−5	−5	−10	410	0	5	0	240	52.5	35	2.25	361	8.0	29.3	9.62
29	D-2	350	−20	−30	−20	410	0	0	5	500	27.5	38	1.75	372	7.0	20.8	8.39
30	S-2	370	−20	−40	−30	410	5	5	10	223	91.3	90	2.0	392	7.9	27.6	8.27
31	D-2	350	−10	−25	−25	410	−5	0	5	500	27.5	38	1.75	372	7.0	20.1	10.75
32	D-1	345	−5	0		410	−5	5		240	52.5	35	2.25	361	8.0	28.0	9.07
33	S-2	370	−25	−40		410	10	5		223	91.3	90	2.0	392	7.9	30.0	9.45
35	S-2	370				410				223	91.3	90	2.0	392	7.9	26.7	9.13
36	S-2	370				410				223	91.3	90	2.0	392	7.9	26.5	7.75
37	S-2	370				410				223	91.3	90	2.0	392	7.9	25.2	8.79
38	S-2	370				410				223	91.3	90	2.0	392	7.9	26.3	9.05
39	S-2	370				410				223	91.3	90	2.0	392	7.9	27.5	8.67
40	D-1	345	−5	−10	−20	410	0	0	5	240	52.5	35	2.25	361	8.0	19.3	8.85
41	D-2	350	−20	−30	−15	410	0	0	5	500	27.5	38	1.75	372	7.0	20.3	9.14
42	S-2	370	−25	−55	−45	410	0	0	5	223	91.3	90	2.0	392	7.9	20.1	8.01
43	D-2	350	−10	−20	−25	410	0	0	0	500	27.5	38	1.75	372	7.0	18.4	8.58

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44	D-1	345	−10	−25	−15	410	0	0	5	240	52.5	35	2.25	361	8.0	23.4	8.70
45	S-2	370	−25	−45	−35	410	0	0	5	223	91.3	90	2.0	392	7.9	17.4	7.02
46	A-1	365	−45	−50	−30	410	−5	−5	0	460	0	11	1.5	378	9.2	20.5	9.53
47	A-2	355	−40	−50	−45	405	−5	−5	5	120	87.5	136	7.0	369	11.9	27.2	9.04
48	S-2	370	−30	−35	−45	410	−5	−5	5	223	91.3	90	2.0	392	7.9	28.3	7.55
49	A-2	355	−25	−45	−40	405	−5	−5	0	120	87.5	136	7.0	369	11.9	26.3	7.83
50	A-1	365	−25	−25	−15	410	−5	0	5	460	0	11	1.5	378	9.2	22.6	8.42
51	S-2	370	−25	−35	−35	410	0	5	0	223	91.3	90	2.0	392	7.9	26.5	8.06
52	S-2	370				410				223	91.3	90	2.0	392	7.9	24.5	8.72
53	B-2	365				420				1,620	0	16	1.0	410	5.8	26.5	8.35
56	S-2	370				410				223	91.3	90	2.0	392	7.9	47.3	9.63
58	S-2	370				410				223	91.3	90	2.0	392	7.9	30.7	8.09
59	S-2	370				410				223	91.3	90	2.0	392	7.9	26.9	8.37
60	B-2	365				420				1,620	0	16	1.0	410	5.8	23.9	8.77
61	S-2	370				410				223	91.3	90	2.0	392	7.9	25.8	10.29
62	C-1	240				400				22	58.2	216	18.0	336	8.9	33.1	9.39
63	S-2	370				410				223	91.3	90	2.0	392	7.9	35.2	10.32
64	S-2	370				410				223	91.3	90	2.0	392	7.9	37.0	11.22

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TABLE 10B.—*Changes in properties of test oils*

[Arranged by oils]

Log	Oil	Viscosity, seconds				Alkali-absorption number				Carbon residue, per cent				Piston carbon, grams	Combustion-chamber carbon, grams	Insolubles, per cent by weight		
		Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours	Initial	Increase after 1 hour	Increase after 4 hours	Increase after 8 hours	Initial	Increase after 1 hour	Increase after 4 hours	Increase after 8 hours			After 1 hour	After 4 hours	After 8 hours
7	S-2	302	−1	+11	+51	0.30	0.0	0.20	0.59	0.10	0.03	0.14	0.34	2.28	5.21	0.044	0.110	0.316
10	S-2	302	0	12	41	.30	.08	.....	.64	.10	.04	.12	.33	1.92	6.38	.021	.088	.273
13	S-2	302	−4	13	55	.30	.13	.29	.74	.10	.04	.08	.37	2.27	6.31	.045	.129	.282
16	S-2	302	−8	7	51	.30	.10	.27	.33	.10	.04	.15	.29	1.52	5.45	.030	.104	.294
19	S-2	302	−8	8	52	.30	.17	.30	.45	.10	.0	.11	.46	1.60	7.07	.019	.090	.275
20	S-2	302	−8	8	54	.30	.19	.57	.89	.10	.02	.15	.38	1.35	5.76	.010	.071	.263
23	S-2	302	−6	12	64	.30	.19	.34	.96	.10	.03	.09	.28	1.66	7.38	.017	.081	.323
26	S-2	302	−8	12	70	.30	.14	.47	.80	.10	.04	.16	.38	2.82	6.40	.009	.162	.523
30	S-2	302	−6	12	59	.30	.26	.31	1.04	.10	.03	.13	.33	1.70	7.90	.007	.102	.358
33	S-2	302	−6	12	66	.30	.20	.53	.53	.10	.0	.09	.36	1.46	8.02	.034	.142	.400
35	S-2	302	.....	.....	61	.30	.....	.....	.....	.10	.....	.....	.36	3.65	9.49	.....	.....	.394
36	S-2	302	.....	.....	44	.30	.....	.....	.....	.10	.....	.....	.36	2.29	9.53	.....	.....	.318
37	S-2	302	.....	.....	45	.30	.....	.....	.....	.10	.....	.....	.....	2.38	8.86	.....	.....	.341
38	S-2	302	.....	.....	50	.30	.....	.....	.....	.10	.....	.....	.....	2.42	10.38	.....	.....	.366
39	S-2	302	.....	.....	44	.30	.....	.....	.....	.10	.....	.....	.....	2.59	8.84	.....	.....	.378
42	S-2	302	−8	−1	41.5	.30	.04	.17	.97	.10	.0	.08	.24	2.52	8.19	.043	.101	.288
45	S-2	302	−8	−1	36	.30	.32	.35	1.09	.10	.0	.07	.26	2.69	8.41	Tr.	.059	.222
48	S-2	302	−7	5	50	.30	.....	.....	.....	.10	.....	.....	.35	2.51	9.04	.....	.....	.327
51	S-2	302	−6	2	48	.30	.....	.....	.....	.10	.....	.....	.32	3.39	8.75	.....	.....	.329
52	S-2	302	.....	.....	43	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.334
56	S-2	302	.....	.....	60	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.751
58	S-2	302	.....	.....	58	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.379
59	S-2	302	.....	.....	61	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.358
61	S-2	302	.....	.....	67	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.456
63	S-2	302	.....	.....	72	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.498
64	S-2	302	.....	.....	80	.30	.....	.....	.....	.10	.....	.....	.....	.....	.....	.....	.....	.599
8	A-1	293	0	15	46	.02	.05	.26	.37	.10	.0	.04	.21	1.36	5.14	.023	.086	.216
12	A-1	293	−1	16	56	.02	.07	.28	.32	.10	.0	.04	.31	1.50	2.96	.025	.082	.240
46	A-1	293	−13	5	54	.02	.11	.20	.....	.10	.0	.06	.22	2.77	8.42	.030	.113	.303
50	A-1	293	−8	4	43	.02	.....	.....	.....	.10	.....	.....	.23	2.88	8.54	.....	.....	.296

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TABLE 10B.—*Charges in properties of test oils*—Continued

Log	Oil	Flash, °F.				Fire, °F.				Demulsibility	Emulsion, per cent	Oxidation number	R. E. number	I. b. p. at 40 mm., °F.	Residue 300 °C. 15 mm.	Total insolubles, pounds / 1,000	Oil consumption, pounds
		Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours	Initial	Change after 1 hour	Change after 4 hours	Change after 8 hours								
7	S-2	370	0	−10	−30	410	5	0	5	223	91.3	90	2.0	392	7.9	28.8	6.13
10	S-2	370	−10	−25	−25	410	−5	0	0	223	91.3	90	2.0	392	7.9	25.9	6.44
13	S-2	370	−20	−20	−25	410		0	0	223	91.3	90	2.0	392	7.9	23.3	7.25
16	S-2	370	−15	−25	−20	410	5	0	0	223	91.3	90	2.0	392	7.9	28.0	6.26
19	S-2	370	−15	−30	−20	410	5	0	10	223	91.3	90	2.0	392	7.9	23.6	7.26
20	S-2	370	−15	−25	−25	410	0	5	5	223	91.3	90	2.0	392	7.9	25.8	6.17
23	S-2	370	−20	−30	−20	410	0	0	5	223	91.3	90	2.0	392	7.9	25.1	8.08
26	S-2	370	−20	−25	−20	410	5	5	5	223	91.3	90	2.0	392	7.9	33.5	9.57
30	S-2	370	−20	−40	−30	410	5	5	10	223	91.3	90	2.0	392	7.9	27.6	8.27
33	S-2	370	−25	−40		410	10	5		223	91.3	90	2.0	392	7.9	30.0	9.45
35	S-2	370				410				223	91.3	90	2.0	392	7.9	26.7	9.13
36	S-2	370				410				223	91.3	90	2.0	392	7.9	26.5	7.75
37	S-2	370				410				223	91.3	90	2.0	392	7.9	25.2	8.79
38	S-2	370				410				223	91.3	90	2.0	392	7.9	26.3	9.05
39	S-2	370				410				223	91.3	90	2.0	392	7.9	27.5	8.67
42	S-2	370	−25	−55	−45	410	0	0	5	223	91.3	90	2.0	392	7.9	20.1	8.01
45	S-2	370	−25	−45	−35	410	0	0	5	223	91.3	90	2.0	392	7.9	17.4	7.02
48	S-2	370	−30	−35	−45	410	−5	−5	5	223	91.3	90	2.0	392	7.9	28.3	7.55
51	S-2	370	−25	−35	−35	410	0	5	0	223	91.3	90	2.0	392	7.9	26.5	8.06
52	S-2	370				410				223	91.3	90	2.0	392	7.9	24.5	8.72
56	S-2	370				410				223	91.3	90	2.0	392	7.9	47.3	9.63
58	S-2	370				410				223	91.3	90	2.0	392	7.9	30.7	8.09
59	S-2	370				410				223	91.3	90	2.0	392	7.9	26.9	8.37
61	S-2	370				410				223	91.3	90	2.0	392	7.9	25.8	10.29
63	S-2	370				410				223	91.3	90	2.0	392	7.9	35.2	10.32
64	S-2	370				410				223	91.3	90	2.0	392	7.9	37.0	11.22
8	A-1	365	10	−25	−20	410	−10	−10	0	460	0	11	1.5	378	9.2	24.4	4.64
12	A-1	365	−15	−25	−25	410	−5	−5	0	460	0	11	1.5	378	9.2	22.7	6.26
46	A-1	365	−45	−50	−30	410	−5	−5	0	460	0	11	1.5	378	9.2	20.5	9.53
50	A-1	365	−25	−25	−15	410	−5		5	460	0	11	1.5	378	9.2	22.6	8.42
9	A-2	355	10	−10	0	405	−10	−5	0	120	87.5	136	7.0	369	11.9	27.1	6.88
11	A-2	355	0	−5	−20	405	−10	0	5	120	87.5	136	7.0	369	11.9	27.7	5.89
47	A-2	355	−40	−50	−45	405	0	−5	5	120	87.5	136	7.0	369	11.9	27.2	9.04
49	A-2	355	−25	−45	−40	405	−5	−5	0	120	87.5	136	7.0	369	11.9	25.3	7.83
14	B-1	370	5	−10	−25	415	5	0	0	480	51.5	56	1.5	405	7.7	23.4	8.29

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18	B-1	370	−15	−30	415	0	−5	−5	480	51.5	56	1.5	405	7.7	24.4	7.29
15	B-2	365	−15		420	0	0	0	1,620	0	15	1.0	410	5.8	22.5	4.82
17	B-2	365	−10		420	0	0	0	1,620	0	15	1.0	410	5.8	22.5	4.35
53	B-2	365			420				1,620	0	16	1.0	410	5.8	23.9	5.77
60	B-2	365			420				1,620		16	1.0	410	5.8	23.9	
21	C-1	340	−10	5	400	−5	0	5	22	56.2	216	18.0	336	8.9	37.3	8.95
25	C-1	340	−15	−5	400	0	0	5	22	56.2	216	18.0	336	8.9	34.6	9.89
62	C-1	340			400			0	22	56.2	216	18.0	336	8.9	33.1	9.89
22	C-2	340+	−10	−10	395	−0	0		405	0	22	9.0	345	12.1	34.4	8.60
24	C-2	340+	−10	−5	395	0	5	5	405	0	22	9.0	345	12.1	30.5	8.83
27	D-1	345	−5	−10	410	0	5	0	240	52.5	35	2.25	361	8.0	29.3	9.62
32	D-1	345	−5		410	−5	0	0	240	52.5	35	2.25	361	8.0	28.0	9.07
40	D-1	345	−5	−20	410	0	0	5	240	52.5	35	2.25	361	8.0	19.3	8.85
44	D-1	345	−10	−15	410	0	0	5	240	52.5	35	2.25	361	8.0	23.4	8.76
29	D-2	350	−20	−20	410	0	0	5	500	27.5	38	1.75	372	7.0	20.8	8.89
31	D-2	350	−10	−25	410	−5	0	5	500	27.5	38	1.75	372	7.0	20.1	10.75
41	D-2	350	−20	−15	410	0	0	5	500	27.5	33	1.75	372	7.0	20.3	9.14
43	D-2	350	−10	−25	410	0	0	0	500	27.5	38	1.75	372	7.0	18.4	8.68

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TABLE 11.—*Viscosity changes, 8-hour engine samples*

[Viscosity changes averaged and corrected in proportion to changes in related runs with reference oil S-2]

Oil	Gross viscosity change					
	First run	Second run	Third run	Average	Correction multiplier [1]	Corrected average
A-1	46	56		51	1	51
A-2	74	70		72	1	72
S-2	51	41	55	49	1	49
B-1	53	52		53	.924	49
B-2	25	30		28	.924	26
S-2	55	51	52	53	.924	49
C-1	128	128		128	.778	100
C-2	133	127		130	.778	101
S-2	54	64	70	63	.778	49
D-1	70	62		66	.754	50
D-2	43	[2] 61		52	.754	39
S-2	70	59	66	65	.754	49
D-1	42	46		44	1.196	53
D-2	41	40		41	1.196	49
S-2	44	42	36	41	1.196	49
A-1	54	43		49	1.089	53
A-2	82	72		77	1.089	84
S-2	36	50	48	45	1.089	49

[1] Correction multiplier is average viscosity increase of S-2 in first three runs divided by average viscosity increase of S-2 runs in each series, respectively.
[2] Burned wrist pin this run.

TABLE 12.—*Formation of insolubles,*[1] *showing corrections and averages*

Oil	Insolubles, per cent by weight in 8-hour samples					
	First run	Second run	Third run	Average	Correction multiplier	Corrected average
A-1	0.216	0.240		0.228	1	0.228
A-2	.310	.288		.299	1	.299
S-2	.316	.273	0.282	.290	1	.290
B-1	.328	.286		.307	1.021	.314
B-2	.227	.230		.229	1.021	.234
S-2	.282	.294	.275	.284	1.021	.290
C-1	.530	.566		.548	.784	.430
C-2	.513	.433		.473	.784	.371
S-2	.263	.323	.523	.370	.784	.290
D-1	.448	.333		.401	.679	.272
D-2	.276	[2] .379		.328	.679	.223
S-2	.523	.358	.400	.427	.679	.290
D-1 [3]	.268	.319		.294	.979	.288
D-2	.300	.246		.273	.979	.267
S-2	.378	.288	.222	.296	.979	.290
A-1	.303	.296		.300	.990	.297
A-2	.386	.310		.348	.990	.344
S-2	.222	.327	.329	.293	.990	.290

[1] Material insoluble in or precipitated by A. S. T. M. specification petroleum naphtha.
[2] Burned wrist pin this run.
[3] This and five that follow are reruns after overhaul.

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TABLE 13.—*Consumption, percentage of insolubles, and temperature factor for test and reference oils*

Log	Consumption, pounds	Insolubles, per cent	Temperature factor
Reference oil (before engine overhaul):			
7	6.13	0.316	65.20
20	6.17	.263	63.25
16	6.26	.294	62.90
10	6.44	.273	63.06
13	7.25	.282	63.42
19	7.26	.275	62.50
23	8.08	.323	61.80
30	8.27	.358	60.75
33	9.45	.400	61.30
26	9.57	.523	63.10
Reference oil (after engine overhaul):			
45	7.02	.222	65.10
48	7.55	.327	67.25
36	7.75	.318	64.80
Reference oil (after engine overhaul)—Con.			
42	8.01	0.288	64.75
51	8.06	.329	67.25
39	8.67	.378	65.60
37	8.79	.341	62.45
38	9.05	.366	66.40
35	9.13	.394	61.68
58	8.09	[1].379	62.30
59	8.37	.358	63.50
52	8.72	.334	65.60
56	9.63	[1].751	60.57
61	10.29	.456	64.60
63	10.32	.498	65.55
64	11.22	.599	66.65

Log	Consumption, pounds [2]	Insolubles, per cent	Temperature factor
A oils:			
8	4.64(c)	0.216	64.50
11	5.89(a)	.288	65.64
12	6.26(c)	.240	64.75
9	6.88(a)	.310	64.40
49	7.83(a)	.310	66.60
50	8.42(c)	.296	67.80
47	9.04(a)	.386	66.30
46	9.53(c)	.303	67.20
B oils:			
17	5.82(c)	.230	61.10
15	6.19(c)	.227	61.94
18	7.29(a)	.286	62.50
14	8.29(a)	.328	66.00
53	8.35(c)	.322	66.90
60	8.77(c)	.339	65.00
C oils:			
22	8.60(c)	0.513	61.40
24	8.83(c)	.433	62.70
21	8.95(a)	.530	63.88
25	9.89(a)	.566	63.40
62	9.89(a)	.437	63.60
D oils:			
29	8.39(c)	.276	57.30
43	8.58(c)	.246	64.50
44	8.76(a)	.319	66.00
40	8.85(a)	.268	61.10
32	9.07(a)	.353	61.10
41	9.14(c)	.300	65.80
27	9.62(a)	.448	62.08
31	10.75(c)	.379	62.80

[1] Run in after new bearing fitted.
[2] Letters (c) and (a) in parenthesis indicate oil of low and high alkali-absorption number, respectively.

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TABLE 14.—*Weights of insolubles formed per pound of oil consumed*

Log	Oil	Oil consumption	Total insolubles	Weight insolubles per pound oil consumed	Log	Oil	Oil consumption	Total insolubles	Weight insolubles per pound oil consumed
		Pounds	*Pounds 1,000*	*Pounds 1,000*			*Pounds*	*Pounds 1,000*	*Pounds 1,000*
7	S-2	6.13	28.8	4.7	36	S-2	7.75	26.5	3.42
8	A-1	4.64	24.4	5.26	37	S-2	8.79	25.2	2.87
9	A-2	6.88	27.1	3.94	38	S-2	9.05	26.3	2.90
10	S-2	6.44	25.9	4.02	39	S-2	8.67	27.5	3.17
11	A-2	5.89	27.7	4.7	40	D-1	8.85	19.3	2.18
12	A-1	6.26	22.7	3.63	41	D-2	9.14	20.3	2.22
13	S-2	7.25	23.3	3.21	42	S-2	8.01	20.1	2.51
14	B-1	8.29	23.4	2.82	43	D-2	8.58	18.4	2.14
15	B-2	6.19	21.5	3.47	44	D-1	8.76	23.4	2.67
16	S-2	6.26	28.0	4.47	45	S-2	7.02	17.4	2.47
17	B-2	5.82	23.1	3.97	46	A-1	9.53	20.5	2.15
18	B-1	7.29	24.4	3.35	47	A-2	9.04	27.2	3.01
19	S-2	7.26	23.6	3.25	48	S-2	7.55	28.3	3.75
20	S-2	6.17	25.8	4.18	49	A-2	7.83	25.3	3.23
21	C-1	8.95	37.3	4.12	50	A-1	8.42	22.6	2.68
22	C-2	8.60	36.4	4.23	51	S-2	8.06	26.5	3.29
23	S-2	8.08	25.1	3.11	52	S-2	8.72	24.5	2.81
24	C-2	8.83	30.5	3.45	53	B-2	8.35	25.5	3.05
25	C-1	9.89	34.6	3.50	56	S-2	9.63	47.3	4.91
26	S-2	9.57	33.5	3.50	58	S-2	8.09	30.7	3.79
27	D-1	9.62	29.3	3.09	59	S-2	8.37	26.9	3.21
29	D-2	8.39	20.8	2.48	60	B-2	8.77	23.9	2.72
30	S-2	8.27	27.6	3.34	61	S-2	10.29	25.8	2.47
31	D-2	10.75	20.1	1.87	62	C-1	9.89	33.1	3.36
32	D-1	9.07	28.0	3.09	63	S-2	10.32	35.2	3.40
33	S-2	9.45	30.0	3.17	64	S-2	11.22	37.0	3.29
35	S-2	9.13	26.7	2.94					

TABLE 15.—*Weights of insolubles formed per pound of oil consumed*

[Arranged by oils and averaged. Weight of insolubles, thousandths of a pound]

Oil	First run	Second run	Third run	Average	Class of oil
A-1	5.26	3.63	----------	4.45	C.
A-2	3.94	4.70	----------	4.10	A.
S-2	4.70	4.02	3.21	3.98	
B-1	2.82	3.35	----------	3.09	A.
B-2	3.47	3.97	----------	3.74	C.
S-2	3.21	4.47	3.25	3.64	
C-1	4.12	3.50	----------	3.81	A.
C-2	4.23	3.45	----------	3.84	C.
S-2	4.18	3.11	3.50	3.60	----------
D-1	3.09	3.09	----------	3.09	A.
D-2	2.48	1.87	----------	2.18	C.
S-2	3.50	3.34	3.17	3.34	----------
S-2[1]	2.94	3.42	2.87 2.90 3.17	----------	----------
D-1	2.18	2.67	----------	2.43	A.
D-2	2.22	2.14	----------	2.18	C.
S-2	3.17	2.51	2.47	2.72	----------
A-1	2.15	2.68	----------	2.42	C.
A-2	3.01	3.23	----------	3.12	A.
S-2	2.47	3.75	3.29	3.17	----------

[1] Five successive runs after overhaul.

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TABLE 16.—*Increase of carbon residue*

[Used oil filtered to remove ash. No correction for change in engine applied, as increase of carbon residue in oil S-2 is practically uniform throughout]

Oil	Final samples first run	Second run	Average	New oil	Average increase
A-1	0.31	0.41	0.36	0.10	0.26
A-2	.52	.47	.50	.11	.39
B-1	.60	.46	.53	.10	.43
B-2	.41	.35	.38	.09	.29
C-1	.56	.61	.59	.15	.44
C-2	.46	.53	.50	.10	.40
D-1	.42	.33	.38	.07	.31
D-2	.29	.36	.33	.09	.24
D-1 (repeat)	.32	.31	.32	.07	.25
D-2 (repeat)	.38	.29	.34	.09	.25
A-1 (repeat)	.32	.33	.33	.10	.23
A-2 (repeat	.48	.48	.48	.11	.37

The following tabulation shows increase in carbon residue for successive runs with reference oil S-2

Log	Carbon residue increase	Log	Carbon residue increase	Log	Carbon residue increase	Log	Carbon residue increase
7	0.34	20	0.38	35	0.36	42	0.24
10	.33	23	.28	36	.36	45	.26
13	.37	26	.38	37		48	.35
16	.29	30	.33	38		51	.32
19	.46	33	36	39	.31		

TABLE 17.—*Carbon from lower surface of pistons, grams*

Oil	First run	Second run	Third run	Average
A-1	1.36	1.50		1.43
A-2	1.31	1.67		1.49
S-2	2.28	1.92	2.27	2.16
B-1	2.00	1.37		1.69
B-2	1.41	1.29		1.35
S-2	2.27	1.52	1.60	1.80
C-1	2.41	2.62		2.52
C-2	1.85	2.02		1.94
S-2	1.35	1.66	2.82	1.94
D-1	3.38	1.94		2.66
D-2	1.65	3.41		2.53
S-2	2.82	1.70	1.46	1.99
S-2[1]	3.65	2.29	2.38 2.42 2.59	2.67
D-1	1.89	2.74		2.32
D-2	3.25	2.42		2.84
S-2	2.59	2.52	2.69	2.60
A-1	2.77	2.88		2.83
A-2	2.46	2.07		2.27
S-2	2.69	2.51	3.39	2.86

[1] Five runs in succession; run in after overhaul.

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TABLE 18.—*Combustion-chamber carbon, grams*

Oil	First run	Second run	Third run	Average	Correction factor	Corrected average
A-1	5.14	2.96		4.05	1.000	4.05
A-2	6.13	5.43		5.78	1.000	5.78
S-2	5.21	6.38	6.31	5.97	1.000	5.97
B-1	8.43	6.87		7.65	.952	7.28
B-2	5.57	5.04		5.31	.952	5.05
S-2	6.31	5.45	7.07	6.28	.952	5.97
C-1	7.99	8.18		8.09	.917	7.42
C-2	8.19	8.52		8.36	.917	7.66
S-2	5.76	7.38	6.40	6.51	.917	5.97
D-1	6.59	7.47		7.03	.802	5.64
D-2	6.98	6.59		6.79	.802	5.45
S-2	6.40	7.90	8.02	7.44	.802	5.97
S-2 [1]	9.49	9.53	8.86 10.38 8.84			
D-1		8.74		8.74	.704	6.16
D-2	10.64	9.97		10.31	.704	7.26
S-2	8.84	8.19	8.41	8.48	.704	5.97
A-1	8.42	8.54		8.48	.684	5.80
A-2	8.12	8.64		8.38	.684	5.23
S-2	8.41	9.04	8.75	8.73	.684	5.97

[1] Five runs in succession; run in after overhaul.

TABLE 19.—*Differences and ratios of values of physical and chemical properties of new test oils*

Oils	Alkali-absorption number		R. E. number		Emulsion, NaOH		Viscosity 100° F., seconds		Oxidation number		Carbon residue, per cent		Light [1] fractions, per cent		Heavy [2] fractions, per cent	
	D [3]	R [4]	D	R	D	R	D	R	D	R	D	R	D	R	D	R
A-2 / A-1	0.49	25.2	5.5	4.7	87.5	-----	4.0	1.01	125	12.4	0.01	1.1	1.8	1.27	2.7	1.29
B-1 / B-2	.97	33.3	.5	1.5	51.5	-----	−5.0	.98	40	3.5	.01	1.1	3.9	2.39	1.9	1.33
C-1 / C-2	.56	15.0	8.5	1.95	56.2	-----	4.0	1.01	194	9.8	.05	1.5	2.0	1.18	−2.2	.80
D-1 / D-2	31	7.2	.5	1.29	25.0	1.9	5.0	1.02	3	1.09	−.02	.78	−.6	.92	1.0	1.14

[1] Fraction boiling below 437° F. at 40 mm.
[2] Fraction boiling above 572° F. at 15 mm.
[3] Difference between numerical values of properties.
[4] Ratio of numerical value of properties.

TABLE 20.—*Differences and ratios of values of property changes and engine test conditions for test oils*

Oils	A-2 / A-1		B-1 / B-2		C-1 / C-2		D-1 / D-2		D-1 [1] / D-2		A-2 [2] / A-1	
	D [2]	R	D	R	D	R	D	R	D	R	D	R
Piston carbon, grams	0.06	1.04	0.34	1.25	0.58	1.30	0.13	1.05	−0.52	0.82	−0.56	0.80
Combustion chamber carbon, grams	1.73	1.43	2.34	1.44	−.27	.97	.24	1.03	−1.57	.85	−.10	.99
Insolubles, per cent	.071	1.31	.078	1.34	.075	1.16	.073	1.22	.024	1.09	.048	1.16
Total insolubles, thousandths of a pound	3.8	1.16	1.6	1.07	2.3	1.07	8.2	1.40	2.0	1.10	4.7	1.22
Viscosity increase, seconds	21	1.41	25	1.89	−2	.98	14	1.27	3	1.07	28	1.57
Oil consumption, pounds	.94	1.17	1.78	1.30	.95	1.11	−.22	.98	−.05	.99	−.54	.94
Horsepower	.8	1.02	1.1	1.03	.6	1.02	1.4	1.04	−1.1	.97	−.6	.98
Temperature factor	1.39	1.01	2.73	1.04	1.59	1.03	1.54	1.02	−1.45	.98	−1.20	.98
Specific fuel consumption	−.013	.976	−.001	.998	−.001	.998	−.022	.961	.013	1.02	.00	1.00
Carbon residue increase, per cent	.13	1.50	.14	1.48	.04	1.10	.07	1.29	.00	1.00	.14	1.61

[1] Reruns after overhaul.
[2] D equals difference; R equals ratio.

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TABLE 21.—*Differences and ratios of maximum and minimum values of runs with reference oil in test series*

Series	A		B		C		D		D[1]		A[1]	
	D[2]	R	D	R	D	R	D	R	D	R	D	R
Piston carbon, grams	0.36	1.19	0.75	1.49	1.47	2.09	1.36	1.93	0.17	1.07	0.88	1.35
Combustion-chamber carbon, grams	1.17	1.12	1.62	1.30	1.62	1.28	1.62	1.25	.65	1.08	.63	1.07
Insolubles, per cent	.043	1.16	.019	1.07	.260	1.99	.165	1.46	.156	1.70	.107	1.48
Total insolubles, thousandths of a pound	5.5	1.24	4.7	1.20	12.0	1.56	5.9	1.21	10.1	1.58	10.9	1.63
Viscosity increase, seconds	14	1.34	4	1.08	16	1.30	11	1.19	8	1.22	14	1.39
Oil consumption, pounds	1.12	1.18	1.00	1.16	3.40	1.55	1.30	1.16	1.65	1.23	1.04	1.15
Horsepower	1.5	1.04	.7	1.02	.6	1.02	1.3	1.04	.5	1.01	1.2	1.03
Temperature factor	1.78	1.03	.92	1.02	1.45	1.02	2.30	1.04	.85	1.01	2.15	1.03
Specific fuel consumption	.006	1.01	.010	1.02	.013	1.02	.023	1.04	.018	1.03	.010	1.02
Carbon-residue increase, per cent	.04	1.12	.17	1.59	.10	1.36	.05	1.15	.02	1.08	.09	1.35

[1] Rerun after overhaul. [2] D equals difference; R equals ratio.

TABLE 22.—*Differences and ratios of average results of runs with reference oil in each test series*

Series	A		B		C		D		D[1]		A[1]	
	D[2]	R	D	R	D	R	D	R	D	R	D	R
Piston carbon, grams	−0.35	0.85	−0.41	0.79	−0.42	0.80	−0.44	0.80	−0.12	0.95	−0.53	0.83
Combustion chamber carbon, grams	.02	1.11	−1.19	.82	1.30	1.21	.69	1.09	−.43	.95	.51	1.06
Insolubles, per cent	−.026	.91	.015	1.05	−.070	.82	−.103	.78	−.012	.96	.052	1.19
Total insolubles, thousandths of a pound	−.2	.99	4.5	1.19	−4.6	.85	−4.2	.87	−2.4	.89	6.3	1.28
Viscosity increase, seconds	−12	.77	−1.5	.95	2	1.03	−9	.87	1.5	1.04	8	1.19
Oil consumption, pounds	−.25	.96	−.99	.86	.81	1.11	−1.24	.87	.16	1.02	.01	1.00
Horsepower	−.77	.98	−.02	.999	−.41	.99	−.49	.99	−.4	.99	.6	1.02
Specific fuel consumption	−.005	.99	.002	1.004	.010	1.02	.015	1.03	.003	1.004	−.006	.99
Carbon residue increase, per cent	−.025	.93	−.125	.70	−.10	.74	−.04	.89	−.02	.92	.06	1.21
Temperature factor	−1.25	.98	−.05	.999	−1.37	.97	−1.45	.98	−.60	.99	1.08	1.02

[1] Reruns after overhaul. [2] D equals difference; R equals ratio.

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TABLE 23A.—*Résumé of differences of values of properties and test results of test and reference oils given in Tables 19 to 22*

Oil	Alkali-absorption number	R. E. number	Emulsion, NaOH, per cent	Viscosity, seconds	Oxidation number	Carbon residue, per cent	Light fractions, per cent	Heavy fractions, per cent	Piston carbon, grams
A-2 / A-1	0.49	5.5	87.5	4.0	125	0.01	1.8	2.7	0.06
S-2 (max.)									.36
S-2 (avg.)									−.35
B-1 / B-2	.97	.5	51.5	−5.0	40	.01	3.9	1.9	.34
S-2 (max.)									.75
S-2 (avg.)									−.41
C-1 / C-2	.56	8.5	56.2	4.0	194	.05	2.0	−2.2	.58
S-2 (max.)									1.47
S-2 (avg.)									−.42
D-1 / D-2	.31	.5	25.0	5.0	3	−.02	−.6	1.0	.13
S-2 (max.)									1.36
S-2 (avg.)									−.44
D-1[1] / D-2	.31	.5	25.0	5.0	3	−.02	−.6	1.0	−.52
S-2 (max.)									.17
S-2 (avg.)									−.12
A-2[1] / A-1	.49	5.5	87.5	4.0	125	.01	1.8	2.7	−.56
S-2 (max.)									.68
S-2 (avg.)									−.53

Oil	Combustion chamber carbon, grams	Insolubles, per cent	Total insolubles, thousandths of a pound	Viscosity increase, seconds	Oil consumption, pounds	Horsepower	Specific fuel consumption, pounds per horsepower hour	Carbon residue increase, per cent	Temperature factor
A-2 / A-1	1.73	0.071	3.8	21	0.94	0.8	−0.013	0.13	1.39
S-2 (max.)	1.17	.043	5.5	14	1.12	1.5	.006	.04	1.78
S-2 (avg.)	.62	−.026	−.2	−12	−.25	−.77	−.005	−.025	−1.25
B-1 / B-2	2.34	.078	1.6	25	1.78	1.1	−.001	.14	2.73
S-2 (max.)	1.62	.019	4.7	4	1.00	.7	.010	.17	.92
S-2 (avg.)	−1.19	.015	4.5	−1.5	−.99	−.02	.002	−.125	−.05
C-1 / C-2	−.27	.075	2.3	−2	.95	.6	−.001	.04	1.59
S-2 (max.)	1.62	.260	12.0	16	3.40	.6	.013	.10	1.45
S-2 (avg.)	1.30	−.070	−4.6	2	.81	−.41	.010	−.10	−1.37
D-1 / D-2	.24	.073	8.2	14	−.22	1.4	−.022	.07	1.54
S-2 (max.)	1.62	.165	5.9	11	1.30	1.3	.023	.05	2.30
S-2 (avg.)	.69	−.103	−4.2	−9	−1.24	−.49	.015	−.04	−1.45
D-1[1] / D-2	−1.57	.024	2.0	3	−.05	−1.1	.013	.00	−1.45
S-2 (max.)	.65	.156	10.1	8	1.65	.5	.018	.02	.85
S-2 (avg.)	−.43	−.102	−2.4	1.5	.16	−.4	.003	−.02	−.60
A-2[1] / A-1	−.10	.048	4.7	28	−.54	−.6	.00	.14	−1.20
S-2 (max.)	.63	.017	10.9	14	1.04	1.2	.010	.09	2.15
S-2 (avg.)	.51	.052	6.3	8	.01	.6	−.006	.06	1.08

[1] Reruns after overhau'

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TABLE 23B.—*Résumé of ratios of properties and test results of test and reference oils given in Tables 19 to 23*

Oil	Alkali-absorption number	R. E. number	Emulsion, NaOH, per cent	Viscosity, 100° F., seconds	Oxidation number	Carbon residue, per cent	Light fractions, per cent	Heavy fractions, per cent	Piston carbon, grams
A-2/A-1	25.5	4.66	87.5	1.01	12.4	1.1	1.21	1.29	1.04
S-2 (max.)									1.19
S-2 (avg.)									.85
B-1/B-2	33.3	1.50	51.5	.98	3.5	1.1	2.39	1.33	1.25
S-2 (max.)									1.49
S-2 (avg.)									.79
C-1/C-2	15.0	1.95	56.2	1.01	9.8	1.5	1.18	.80	1.30
S-2 (max.)									2.09
S-2 (avg.)									.80
D-1/D-2	7.2	1.29	1.9	1.02	1.1	.8	.92	1.14	1.05
S-2 (max.)									1.93
S-2 (avg.)									.80
D-1[1]/D-2	7.2	1.29	1.9	1.02	1.1	.8	.92	1.14	.82
S-2 (max.)									1.07
S-2 (avg.)									1.05
A-2[1]/A-1	25.5	4.66	87.5	1.01	12.4	1.1	1.21	1.29	.80
S-2 (max.)									1.35
S-2 (avg.)									.83

Oil	Combustion chamber carbon, grams	Insolubles, per cent	Total insolubles, thousandths of a pound	Viscosity increase, seconds	Oil consumption, pounds	Horsepower	Specific fuel consumption, pounds per hp. hour	Carbon residue increase, per cent	Engine factor
A-2/A-1	1.43	1.31	1.16	1.41	1.17	1.02	0.976	1.50	1.01
S-2 (max.)	1.12	1.16	1.24	1.34	1.18	1.04	1.01	1.12	1.03
S-2 (avg.)	1.11	.91	.99	.77	.96	.98	.99	.93	.98
B-1/B-2	1.44	1.34	1.07	1.89	1.30	1.03	.998	1.48	1.04
S-2 (max.)	1.30	1.07	1.20	1.08	1.16	1.02	1.02	1.59	1.02
S-2 (avg.)	.82	1.05	1.19	.95	.86	1.00	1.00	.70	1.00
C-1/C-2	.97	1.16	1.07	.98	1.11	1.02	.998	1.10	1.03
S-2 (max.)	1.28	1.99	1.56	1.30	1.55	1.02	1.02	1.36	1.02
S-2 (avg.)	1.21	.82	.85	1.03	1.11	.99	1.02	.74	.97
D-1/D-2	1.03	1.22	1.40	1.27	.98	1.04	.961	1.29	1.02
S-2 (max.)	1.25	1.46	1.21	1.19	1.16	1.04	1.04	1.15	1.04
S-2 (avg.)	1.09	.78	.87	.87	.87	.99	1.03	.89	.98
D-1[1]/D-2	.85	1.09	1.10	1.07	.99	.97	1.00	1.00	.98
S-2 (max.)	1.08	1.70	1.58	1.22	1.23	1.01	1.03	1.08	1.01
S-2 (avg.)	.95	.96	.89	1.04	1.02	.99	1.00	.92	.99
A-2[1]/A-1	.99	1.16	1.22	1.57	.94	.98	1.02	1.61	.98
S-2 (max.)	1.07	1.48	1.63	1.39	1.15	1.03	1.02	1.35	1.03
S-2 (avg.)	1.06	1.19	1.28	1.19	1.00	1.02	.99	.90	1.02

[1] Reruns after overhaul.

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